CITIES AND CLIMATE CHANGE

Responding to an Urgent Agenda

Volume 2

CITIES AND CLIMATE CHANGE

Responding to an Urgent Agenda

Daniel Hoornweg, Mila Freire, Marcus J. Lee,
Perinaz Bhada-Tata, and Belinda Yuen, editors

THE WORLD BANK
Washington, D.C.

Volume 2

Contents

Foreword

The 5th Urban Research Symposium on Cities and Climate Change Responding to an Urgent Agenda, held in Marseille in June 2009, aimed to highlight how climate change and urbanization are converging to present us with one of the greatest challenges of our time. Responding to these twin challenges effectively and sustainably is a key objective for governments, authorities, institutions and other organizations involved in urban development processes. The World Bank, the French Ministry of Ecology, Energy, Sustainable Development and the Sea, and the French Development Agency were therefore particularly committed to the co-organization of the Symposium.

As the ultimate source of much of the world's energy consumption, and thus greenhouse gas emissions, cities have a key role to play in mitigating climate change. To varying extents, cities are also vulnerable to climate change impacts, with poor populations facing the greatest risk, such that adaptation and increased resilience constitute priorities for every city. Consequently, climate change mitigation and adaptation in cities has emerged as a new theme on the global agenda, creating a strong desire among governments, the private sector and the academic community worldwide to learn from experiences and good practice examples.

The 5th Urban Research Symposium made an important contribution to the growing body of knowledge and practice in the area of cities and climate change. During the three day Symposium, approximately 200 papers were presented to over 700 participants representing more than 70 countries. As co-organizers, we found it very rewarding to have such an audience and to see the wide range of topics discussed, from indicators and measurement, to institutions and governance. This publication represents an edited selection of the many papers submitted to the Symposium and gives a flavor of the questions asked and possible answers. Besides, the entire collection of Symposium papers is available as an online resource for interested readers.

The Symposium was made possible through the commitment and contributions of a wide range of partners and co-sponsors, as well as through the interest and participation of the wider community of urban researchers and practitioners. We were encouraged by the success of the Symposium which exceeded many expectations, and therefore wish to further disseminate its results via a publication of collected papers. We look forward to the benefits that the partnerships forged during the Symposium, and the knowledge gained, will have for global efforts on cities and climate change.

Inger Andersen
Vice President
Sustainable Development Network
The World Bank

Michèle Pappalardo
General Commissioner for Sustainable Development
Ministry of Ecology, Energy, Sustainable Development and the Sea

Pierre Jacquet
Chief Economist
Executive Director (Strategy)
French Development Agency

Acknowledgements

The 5th Urban Research Symposium was co-organized by the World Bank, the French Ministry of Ecology, Energy, Sustainable Development and the Sea (MEEDDM), and the French Agency for Development (AFD). The Symposium's Steering Group included Abha Joshi-Ghani, Mila Freire, and Daniel Hoornweg of the World Bank; Aude Vermot-Gaud and Anne Charreyron-Perchet of MEEDDM; and Nils Devernois and Laureline Krichewsky of AFD. The Symposium's Scientific Committee comprised Yves Crozet, Mila Freire, Pierre-Noel Giraud, Bernd Hansjuergens, Sylvy Jaglin, Andrew Norton, and William Solecki.

The Symposium Secretariat was led by Jean-Jacques Helluin and Perinaz Bhada at the World Bank. Many World Bank colleagues provided helpful comments at every stage during the Symposium's development, from the initial concept note review through to the Symposium itself. Excellent organizational and administrative support for the Symposium was provided by Adelaide Barra, Viviane Bernadac, Louis Blazy, Laura de Brular, Vivian Cherian, Xiaofeng Li, Maria Eugenia Quintero, and Berenice Sanchez. Thanks also go to Zoubida Allaoua and Kathy Sierra of the World Bank, and Robert Peccoud and Veronique Sauvat at AFD, for their guidance and leadership.

The institutional and strategic partners who generously contributed to the Symposium included the French Environment and Energy Management Agency (ADEME), Caisse des Dépôts, the Cities Alliance, the Dexia Group, the Euromedina Urban Network, the European Commission, the Fonds Français pour l'Environnement Mondial (FFEM), the French Ministry of Foreign Affairs, GDF SUEZ, German Federal Ministry of Education and Research, the Global Environment Facility (GEF), GTZ, ICLEI – Local Governments for Sustainability, the Institut des Sciences et des Techniques de l'Equipement et de l'Environnement pour le Développement (ISTED), the International Development Research Centre (IDRC), the International Society of City and Regional Planners (ISOCARP), the

Lincoln Institute of Land Policy, the City of Marseille, Metropolis, the Organization for Economic Cooperation and Development (OECD), United Cities and Local Governments (UCLG), the UK Department for International Development (DFID), the United Nations Environment Programme (UNEP), UN-HABITAT, the United Nations Population Fund (UNFPA), the Urban Climate Change Reseach Network (UCCRN), and Veolia Environnement. The World Bank's Energy Sector Management Assistance Program (ESMAP) commissioned some researchers and produced a related publication.

Much appreciation is due to the authors of all papers submitted and presented at the Symposium, as well as to all Symposium participants whose ideas and contributions provided for rich and lively discussions during the various sessions. The authors of the eight commissioned research papers helped to synthesize and strengthen the knowledge presented at the Symposium, including through the preparatory workshop for commissioned researchers.

Preparation of the online volume of this publication involved a team from the Urban and Local Government Unit of the World Bank, comprising Christa Anderson, Julianne Baker Gallegos, Mila Freire, Daniel Hoornweg, Marcus Lee, Pascaline Ndungu and Belinda Yuen, with assistance from Adelaide Barra. Technical and substantive editing was ably undertaken through a team comprising Anu Ramaswami, Sebastian Carney, Elliot Cohen, Shobhakar Dhakal, Enessa Janes, Christopher Kennedy, Cynthia Skelhorn, and Joshua Sperling. Useful comments were received from the peer reviewers, Ellen Hamilton, Susan Parnell and Federica Ranghieri. Renée Saunders provided design services for this online volume.

Introduction

Cities and the Urgent Challenges of Climate Change

The Challenge of Cities and Climate Change

Climate change is among the most pressing challenges that the world faces today. Given current atmospheric concentrations of greenhouse gases (GHGs), the world is already committed to significant warming. This is a serious challenge, given the wide range of expected climate impacts on natural systems as well as on human societies, as assessed in the most recent report of the Intergovernmental Panel on Climate Change (IPCC 2007). The severity of these impacts will depend in part on the outcomes of global efforts to mitigate climate change. Yet developing countries and poor populations everywhere remain the most vulnerable to the impacts of climate change. Even as poverty reduction and sustainable development remain at the core of the global agenda—as emphasized in the *World Development Report 2010: Development and Climate Change*—climate change threatens to undermine the progress that has been achieved to date (World Bank 2010a).

Urbanization is a defining phenomenon of this century. Developing countries are at the locus of this transformation, as highlighted in the World Bank's 2009 Urban Strategy. It is often repeated that more than half of the world's population is now urban. Most of the population of industrialized countries is urban, with numerous developing countries, particularly in Latin America, also highly urbanized (UN 2010). Many developing countries in other regions of the world are following the same path. This transformation represents a challenge, but also a huge opportunity—the *World Development Report 2009: Reshaping Economic Geography* (2009) framed this in a new paradigm, to harness the growth and development benefits of urbanization while proactively managing its negative effects.

Cities concentrate wealth, people, and productivity, but they also concentrate vulnerability to natural disasters and to long-term changes in climate. Rising sea levels will affect millions of people living in coastal cities. Similarly, migration, changes in land use, and spatial development are likely to increase the vulnerability of populations to changes in weather and climatic conditions. Adaptation to climate change is therefore an imperative for cities, as it is for the world at large. The urgency of this challenge is also evident when considering the massive investments in buildings and infrastructure that cities in developing countries will undertake in the coming years, which will lock in urban form and structure for many decades thereafter.

The 5th Urban Research Symposium

The links between cities and climate change were the subject of the 5th Urban Research Symposium held in Marseille in June 2009. Under the main theme, *Cities and Climate Change—Responding to an Urgent Agenda,* the symposium aimed to advance the state of knowledge on cities and climate change from an applied research perspective. Attended by more than 700 people from more than 70 countries, the symposium featured eight teams of commissioned researchers and approximately 200 research papers selected from more than 500 initial proposals. The symposium was a groundbreaking event, given its scale and its focus on cities and climate change.

The symposium's research topics were organized around five clusters. The first dealt with *models and indicators to measure impact and performance of cities*. The complexity that characterizes climate change at the global level is heightened at the city level by the need to define boundaries, identify consumers and producers, and understand intercity flows. This is also the area where progress has been the most visible, with international partnerships and committed local governments working together to harmonize concepts and improve data collection. In turn, the increased availability of data and indicators stimulates research to test and apply global models at the city level.

The second cluster focused on *infrastructure, the built environment, and energy efficiency.* This area received the largest number of papers, covering issues from urban heat islands to urban transport policies and energy conservation. The insights from this cluster are important given the massive investments that cities in the developing world are expected to make in coming decades. Cities are also eager to share progress and discuss solutions that have worked elsewhere. Complementing this volume, the Energy Sector Management and Assistance Program (ESMAP) at the World Bank has published selected papers from this cluster on energy efficiency in cities (Bose 2010).

The third cluster dealt with *finance and the economic incentives related to* *climate change*. The papers in this cluster focused more on financing requirements and the difficulties that cities may face in meeting these requirements, and less on the use of market-based instruments and policies such as carbon finance, taxes, or incentives to change behaviors or encourage intercity collaboration. The fourth and fifth clusters were concerned with the areas of *institutions and governance* and the *social aspects of climate change*. Both clusters produced important papers demonstrating the value of early commitment and participation in cities, as well as the potential to use local development initiatives for mainstreaming climate change concerns in cities.

The eight commissioned research papers are representative of the five clusters and cover issues such as the measurement of GHG emissions, city indicators, energy efficiency in buildings, and the importance of urban form. Papers were commissioned to ensure that leading, cutting-edge research was the organizing principle of the symposium and to provide better coverage of climate risk assessment and resilience, the role of institutions and governance, and the social aspects of climate change.

The symposium was an intense and research-rich three-day learning event. It became clear that experts and academics have differing views on any number of questions, but the areas of consensus are far greater than the areas of divergence. Although researchers continue to improve our knowledge of the world, decision makers cannot wait for all doubts or differences to be resolved. Moving forward, there is increasing urgency to get cities involved in climate change, not only in taking greater leadership roles but also in contributing to cutting-edge research at the city scale, defining practical solutions for urban and periurban areas, and ensuring that research is translated into local policy options. The symposium represents a start on this longer-term journey in understanding the links between cities and climate change—the body of research and projects on cities and climate change continues to grow rapidly.

This online publication presents an edited selection of 34 papers from the symposium that cover both climate change mitigation and adaptation. Examples and case studies from cities in industrialized and developing countries are included, and attention is paid to the perspectives of the poor in adapting to climate change. Of necessity, these papers represent a portion of the vast and rich range of knowledge brought together by the symposium. A selection of eight symposium papers has been published as a printed book. The complete set of symposium papers is available on the symposium's website, accessible through www.worldbank.org/urban.

The rest of this introduction presents the main conclusions and key messages emerging from the symposium, from across all five clusters. These are organized broadly into sections on mitigation and adaptation, with a final section on priorities for future work.

Cities and Climate Change Mitigation

Cities are critical in global efforts to mitigate climate change. Although questions remain about how exactly GHG emissions should be attributed geographically, most of the world's GHG emissions are ultimately attributable to cities, which are centers of economic activity. Cities are responsible for two-thirds of global energy consumption, and this proportion is expected to grow further (IEA 2008). Yet, because of their density, efficiency, and adoption of innovations and new technologies, cities can also provide solutions for reducing emissions.

Measuring City GHG Emissions

A fundamental step for cities when it comes to climate change mitigation is to quantify the GHG emissions attributable to cities. Emissions must be measurable to be manageable; cities will otherwise not be able to set meaningful targets for emissions reductions, track progress toward achieving such targets, or obtain financing readily. In response to this need, much has already been achieved at the city level. ICLEI's Cities for Climate Protection (CCP) campaign, for example, features a five-milestone process that includes establishing a baseline emissions inventory. In 2009 CCP had grown to include over 1,000 local governments worldwide (ICLEI 2010).

Various methodologies for measuring city GHG emissions have been developed in Europe and North America—such as Bilan Carbone, the Greenhoue Gas Regional Inventory Protocol (GRIP), the International Local Government Greenhouse Gas Emissions Protocol (IEAP), and Project 2 Degrees—raising questions of consistency and comparability. Although most efforts have sought to follow IPCC guidelines, considerable variation is found among these methodologies, for example, in terms of the GHGs covered and in terms of the sectors (e.g., energy, waste, transport, and embodied emissions in food and other materials consumed) included (Bader and Bleischwitz 2009). Significant questions exist with regard to the treatment of emissions associated with transport to and from a city and of emissions embodied in materials consumed within a city but produced outside it. Another basic methodological issue lies in the definition of the city for the purpose of measuring emissions, whether based on administrative borders, a defined metropolitan area, or a functional economic space. In many developing country cities, the availability and reliability of data also present a challenge.

The chapter in this volume by Kennedy and others, "Greenhouse Gas Emissions Baselines for Global Cities and Metropolitan Regions," addresses these issues directly and reviews existing methodologies and available published results for various cities. Using a consistent, harmonized methodology, the authors have calculated per capita emissions for more than 40 cities around the world. This demonstrates that consistency and comparability are possible and constitutes a seminal contribution to the joint effort between the United Nations Environment Programme (UNEP), UN-HABITAT, and the World Bank to advance an open, international standard to measure GHG emissions from cities. Unsurprisingly, the results reveal that per capita emissions tend to be higher in the cities of industrialized countries compared with developing country cities. Furthermore, although these results show that per capita emissions in cities are generally lower than corresponding national per capita emissions, recent research on U.S. cities suggests that when emissions embodied in materials consumed in cities are taken into account, city per capita emissions are in fact very close to national per capita emissions (Hillman and Ramaswami 2010).

Factors Influencing City Emissions

A variety of factors influence a city's emissions profile in complex ways. These factors include urban form and land use patterns, climate, building design and technology, transport modes, and income levels. One would naturally expect lower per capita emissions in a city with more energy-efficient buildings, higher rates of public transport use, or lower income levels. The relative importance of such factors is explored by Croci and others in their chapter, "A Comparative Analysis of Global City Policies in Climate Change Mitigation," which includes case studies of Bangkok, London, Mexico City, Milan, and New York City. The authors identify income levels as a major factor in explaining the level of city emissions, while also noting a number of methodological issues in calculating emissions—Bangkok, for instance, estimates transport emissions from fuels consumed within the city, whereas the other cities use vehicle-kilometers traveled.

The emissions profiles of cities can be very different, depending on specific city contexts. Croci and others point this out clearly in their comparison of cities across industrialized and developing countries. The largest contributor to emissions in Bangkok is the transport sector, but in London and New York City it is the buildings sector—specifically energy consumption in residential and commercial buildings, with transport coming second. Bangkok's climate, income level, urban form, and transport systems are all factors that explain this difference. The implication for mitigation in cities is that although cities can certainly learn from one another when developing and implementing mitigation strategies, specific solutions and mitigation measures may not be easily transferable or directly relevant for other cities.

The Importance of Urban Form for Emissions

Perhaps of greatest interest for urban planners and managers is the issue of urban form and density. It has long been known that denser cities tend to have lower per capita energy consumption (see, for example, Newman and Kenworthy 1989) and therefore lower per capita emissions, and that within a given city, per capita emissions are lower in the denser parts of the city. Although this received wisdom has been questioned (Mindali, Raveh, and Salomon 2004), these correlations have been confirmed in recent work, including from the symposium papers and from research cited in the *World Development Report 2010* (World Bank 2010a). Yet urban form is shaped over longer time horizons, through planning, policy, and investment decisions.

In the chapter "GHG Emissions, Urban Mobility, and Efficiency of Urban Morphology," Bertaud and others use the examples of Mumbai, New York City, and Singapore to show how price signals—including energy prices and carbon market–based incentives—are a key factor in reducing GHG emissions from urban transport, in combination with land use and transport planning and policies. They suggest that monocentric cities and density can be managed with the right policies, and that emissions from monocentric cities can be reduced if demand for transport between suburbs and the center increases. In their examination of the factors explaining differences in demand for urban transport, the authors consider how significant reductions in GHG emissions from urban transport can be achieved through technological change to reduce carbon content and through a shift in transport mode from private cars to public transit. The use of energy pricing based on carbon content would promote both of these changes.

The demand for urban transport also depends on urban spatial structures. Bertaud and others go on to show how in all three cities, spatial policies, including floor area ratios (FARs), have played an important role. New York City and Singapore have been able to maintain a high level of transit share by mandating high FARs, prioritizing and improving connections to public transport, ensuring high levels of amenities that make downtown areas attractive, and promoting mixed-use developments located at integrated transport hubs.

Governance Matters for Climate Mitigation in Cities

Armed with a growing understanding of their GHG emissions, many cities are already at the forefront of the mitigation challenge, with subnational efforts in these communities proceeding even as global climate change negotiations have made limited progress. Cities are leading and positioning themselves as a significant part of the solution. Although cities in the industrialized world such as Chicago, London, or New York City are oft-cited examples, cities across various developing countries, such as Cape Town, Mexico City, and São Paulo, are also rising to the challenge. Climate change mitigation plans and responses do vary among cities, as shown in the examples studied by Croci and others—London has adopted a long-term emissions reduction goal with intermediate steps, New York

City and Milan have chosen medium-term targets, and Bangkok and Mexico City have shorter-term targets for 2012. All of this is encouraging, because cities offer humanity the best way to efficiently provide critical services and allocate increasingly scarce resources.

The importance of governance for climate action in cities is demonstrated clearly by Bulkeley and others in their chapter, "The Role of Institutions, Governance and Planning for Mitigation and Adaptation by Cities." The authors provide a comprehensive global review of the current state of mitigation and adaptation action by cities, focusing mainly on cities in the South. Selected case studies include Beijing, Cape Town, Hong Kong, New Delhi, Melbourne, Mexico City, Mumbai, São Paulo, Seoul, and Yogyakarta. They examine how these cities are taking action in three key sectors: buildings, transport, and urban infrastructure. Issues of governance are dominant when it comes to regulating GHG emissions, providing services, and working with other jurisdictions. Key factors that shape responses to mitigation at the local level include effective policy making, access to additional finance, the congruence between jurisdictional areas and the spatial scale at which problems present themselves, and municipal competencies in key areas such as energy, planning, and transport. Governance at the city scale matters, as do the links and relationships with institutional and governance arrangements at other spatial scales.

Fast-growing cities offer enormous opportunities for investments in new energy-efficient technologies and for increasing the amount of energy from alternative and renewable energy sources. As demonstrated in the chapter by Croci and others, the energy sector usually offers the greatest potential, with cities' mitigation efforts accordingly focused on promoting energy efficiency (particularly through standards and regulations for buildings) and striving for lower carbon intensity in the energy supply. Across most cities, transport is the second most important sector, with policies focused on encouraging public transportation instead of the private automobile. Many symposium papers reflected the wide-ranging body of research on green buildings and energy efficiency. These include low-energy redevelopment in Rotterdam (van den Dobbelsteen and others), options for increasing energy efficiency in Nigerian buildings (Akinbami and Lawal), rainwater harvesting and evaporative cooling in Germany (Schmidt), and sustainable house construction in France (Floissac and others).

The motivations of cities and city stakeholders for engaging in climate mitigation also need to be understood. Warden's chapter, "Viral Governance and Mixed Motivations," describes some of the factors that led to American cities committing to address climate change and to the launch of the U.S. Conference of Mayors' Climate Protection Agreement (USMCPA) in 2005. The USMCPA has been very successful in motivating mayors in the United States, with more than 1,000 mayors signed on in 2010 (U.S. Conference of Mayors 2010). Growing public awareness, a flexible framework agreement, and having participants as proponents all contributed to the "viral" spread of climate engagement among U.S. cities. The USMPCA remains valuable because of its ability to generate awareness and engage a large number of cities on the issue of climate change. Although focused on the U.S. experience, Warden's analysis indirectly helps to advance our understanding of the engagement of cities worldwide on climate change issues, through international networks such as ICLEI and the C40 cities.

A key observation is that, globally, climate change action among cities is focused more on mitigation than on adaptation. This is a point advanced by Bulkeley and others and reinforced by the analyses of Croci and others and Warden. The broad field of proposals submitted to the symposium also reflected a bias toward mitigation. This is the case even among cities in developing countries, even though these cities tend to have lower per capita emissions and thus would have relatively fewer mitigation opportunities. These cities' vulnerability to the impacts of climate change would also suggest an urgent need to focus on adaptation issues. Although various explanations have been advanced, such as the need for greater institutional capacity in developing countries, further research exploring this relative emphasis on mitigation is needed, as is strengthened understanding of how and why cities are motivated to undertake action on adaptation.

Cities and Climate Change Adaptation

Given that cities are concentrated centers of population and economic activities, any impact or disruption, whether natural or human-induced, has the potential to affect vast numbers of people. The expected impacts of climate change pose a massive challenge to cities. These impacts will vary from city to city, as well as within a city. For instance, coastal cities are vulnerable to rising sea levels, more intense precipitation increases the likelihood of flooding in low-lying areas and landslides on steep slopes, and extended heat waves are a threat to cities unaccustomed to very hot summers. In every city, the poorest populations are the most vulnerable, because they have the least adaptive capacity and often occupy areas that are more exposed to hazards. Building resilience and adapting to climate change are therefore a high priority for cities. Yet city managers and practitioners serving the urban poor often point out that the multiple competing priorities of today are challenging enough; paying attention to uncertain future climate impacts is thus seen as a lower priority. In light of this, better appreciation of the cobenefits from urban poverty reduction and adaptation to climate change is needed.

Cities Responding to the Adaptation Challenge

In spite of the emphasis on mitigation thus far, and the many existing pressing needs faced by city managers and practitioners, there is a growing body of research and practice on adaptation in cities. Again, cities in industrialized countries are commonly cited as examples of good practice in adaptation planning, but cities in developing countries are also increasingly interested and active in this area. Heinrichs and others present findings from eight cities (Bogota, Cape Town, Delhi, the Pearl River Delta, Pune, Santiago de Chile, São Paulo, and Singapore) in their chapter, "Adapting Cities to Climate Change: Opportunities and Constraints." The full collection of symposium papers also reflected this trend of increased activity in climate adaptation among developing country cities, for example, in the papers by Carmin and others, which examined the cases of Durban and Quito, and by Dodman and others on community-level responses in the Philippines. Together, these papers show that far from being laggards, in many cases developing country cities are the ones turning out to be the first movers and innovators when it comes to preparing for, and adapting to, future climate impacts.

Several key enabling factors can be identified among those cities that are already responding to the adaptation challenge. The importance of identifying these enabling factors cannot be overemphasized, because these are essential for ensuring that cities are able to adapt. Bulkeley and others argue that these factors largely fall under the area of institutions and governance, which suggests that efforts to strengthen institutional and governance capacities in general at the city level would have the cobenefit of enabling better responses for adaptation. Heinrichs and others highlight several factors that also emerge across the wider collection of studies, including the availability of information, the need for higher levels of awareness, synergies with existing priorities and programs, the existence of strong leadership, availability of dedicated resources, and adequate technical and financial capacities.

Understanding Climate Impacts in Cities

One basic requirement for adaptation planning in any city is a sound analysis of possible climate impacts. In itself, this is a challenge of substantial complexity—there is considerable uncertainty of what future climate impacts might be for a given city, although our knowledge and modeling capabilities are constantly improving, for example, with downscaling climate models. In "Urban Heat Islands: Sensitivity of Urban Temperatures to Climate Change and Heat Release in Four European Cities," McCarthy and Sanderson show how urban areas can be included in regional climate models, using the cases of Athens, Cairo, London, and Moscow. The authors focus on the "urban heat island" effect, which arises from heat released through human activity in cities, such as the heating and cooling of buildings, traffic exhaust, and even human metabolism. Urban buildings and structures absorb heat during the daytime and release it at night, leading to an increase in nighttime temperatures. The authors caution that future heat waves may be underestimated if finer features at the urban scale are not included in model simulations. The potential for applying this analysis to other cities is considerable and would enable individual cities to fine-tune their knowledge of potential changes in local temperatures.

In general, modeling efforts are well situated within a broader field of work on assessing climate risks in cities. Bulkeley and others and Heinrichs and others analyze how cities are already anticipating and planning for future climate impacts. One of the symposium's commissioned research papers by Mehrotra and others also addressed this need: it presented a framework for climate risk assessment in cities and emphasized the importance of distinguishing among the different types of risks faced by different cities. The forthcoming Urban Risk Assessment, an approach for assessing disaster and climate risk in cities, is being developed by the World Bank with UNEP and UN-HABITAT and proposes a unified methodology for this purpose. It represents another important step in bringing the fields of disaster risk management and climate change adaptation closer. Although both communities of practice have the common aim to support decision making under uncertainty, they have largely operated in isolation from each other until recently (Tearfund 2008).

Climate Adaptation and the Urban Poor

An important issue when considering climate change adaptation, especially in developing countries, is to ensure adequate focus on the urban poor. Significant literature can be found on the economic impacts and costs of adaptation to climate change (see, for example, World Bank 2010b). Evidence is also available that the number of people affected by disasters is on the rise, and that within cities most disaster-related injuries and deaths occur among low-income groups (UN-HABITAT 2007). Moser and Satterthwaite (2008) clearly demonstrate that the main driver of increasing loss of life is poverty, which limits individual and household investments, and exclusion, which limits access to public services. In this context, not only does climate change exacerbate the existing vulnerabilities of the poor, but it also creates new risks as more areas in a city are exposed to climate-related hazards. The urgency is increased in those cities in developing countries with high concentrations of vulnerable urban poor.

A framework for focusing on the urban poor is provided by Moser in "A Conceptual and Operational Framework for Pro-Poor Asset Adaptation to

Climate Change," which shows how the vulnerability of the urban poor's assets can be analyzed and offers examples of asset-based adaptation responses. Vulnerability varies depending on hazard exposure and the capacity to cope and adapt; these in turn depend on factors such as settlement quality and infrastructure provision. At the individual level, factors such as age, gender, and social status also matter. Greater assets (both intellectual and physical) reduce vulnerability and improve the capacity of the individual and community to react and adapt to disasters, including postdisaster reconstruction.

A closer understanding of specific vulnerabilities is also useful for taking concrete actions. Because many poor settlements are located in vulnerable places or lack protective infrastructure, long-term resilience can be increased by identifying better locations, increasing property ownership, and improving infrastructure. At the community level, improving community capacity and resilience is essential. The paper by Bartlett and others on the social aspects of climate change in urban areas, together with the paper by Dodman and others, reveals how community-based organizations and initiatives can be very effective in enabling adaptation among disadvantaged city dwellers.

An emerging conclusion is that the key to adaptation among the urban poor is to continue to address the basic poverty reduction and sustainable development agenda in cities to improve the livelihoods and resilience of the poor—ensuring adequate and effective delivery of services such as health, education, water, energy, public transport, and waste management; providing safety nets and increasing food security; upgrading facilities and infrastructure in slums and other informal settlements; and providing security of tenure and property rights.

Priorities for Future Work

Although the foregoing discussion has distinguished clearly between mitigation and adaptation to climate change, responding to the complex challenges of climate change in cities does not always lend itself to distinct categorizations in terms of mitigation or adaptation. Comprehensive and integrated approaches, which include both mitigation and adaptation strategies and the synergies between them, are needed to fully address this challenge. They also offer opportunities for cities to identify and take advantage of co-benefits; for example, investments in energy efficiency in buildings can both reduce GHG emissions and increase resilience in the face of more extreme weather conditions. Although much work is already taking place on integrated approaches that deliver co-benefits, greater awareness of these is needed, as is broader implementation in the field, beyond demonstration and piloting.

The symposium—its papers, presentations, and discussions—reveals numerous areas in which further research is required to strengthen diagnosis and policies at the local level, building on what is already underway. Several of these are highlighted here. First, the advances made to measure and analyze city GHG emissions need to be consolidated and eventually lead to internationally accepted methodologies used with the same rigor and accountability by cities in both the North and the South. This will ensure that mitigation efforts are well targeted within cities with progress toward mitigation targets properly tracked, and this clarity and consistency will facilitate access to additional finance. Second is the need to continue to expand work on adaptation in cities, in terms of both understanding future climate impacts and implementing the most effective adaptation actions in response to specific risks including disasters. Third, we need to increase our knowledge of the unique circumstances of developing country cities, because considerable variation is found among these cities across regions and across different city sizes and locations. Fourth is the need to undertake further economic and social analyses of all aspects of climate change in cities; this was especially apparent from the relatively small proportion of papers at the symposium on economic and social issues: only a handful of papers addressed the crucial issue of financing climate actions in cities. The costs and benefits of (non) action, social influences, and behavioral studies are central to understanding the basis of public attitudes and behavior for effective climate change action. Last but not least, data availability is a critical constraint, for which continued efforts in data collection and utilization are needed.

The overwhelming response to the symposium far exceeded initial expectations. It is clear that the field of research on cities and climate change is growing and rapidly evolving, which bodes well to ensure that the best knowledge and analysis is applied to the urgent challenges that cities face in responding to climate change. The World Bank and its partners are committed to working with cities, researchers, and other agencies to improve the well-being of cities and their residents, especially the poor and the vulnerable.

References

Bader, N., and R. Bleischwitz. 2009. *Study Report: Comparative Analysis of Local GHG Inventory Tools.* Bruges: College of Europe and Paris: Institut Veolia Environnement.

Bose, R. K., ed. 2010. *Energy Efficient Cities. Assessment Tools and Benchmarking Practices.* Washington, DC: World Bank.

Hillman, T., and A. Ramaswsami. 2010. "Greenhouse Gas Emission Footprints and Energy Use Benchmarks for Eight U.S. Cities." *Environmental Science and Technology* 44 (6): 1902-1910. DOI: 10.1021/es9024194.

ICLEI. 2010. "Cities for Climate Protection (CCP) Campaign." http://www.iclei.org/index.php?id=10829.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: *The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IEA (International Energy Agency). 2008. *World Energy Outlook 2009.* Paris: International Energy Agency.

Mindali, O., A. Raveh, and I. Salomon. 2004. "Urban Density and Energy Consumption: A New Look at Old Statistics." *Transportation Research Part A: Policy and Practice* 38(2): 143–162.

Moser, C., and D. Satterthwaite. 2008. "Towards Pro-Poor Adaptation to Climate Change in the Urban Centres of Low- and Middle-Income Countries." Human Settlements Discussion Paper Series, Climate Change and Cities 3, IIED/GURC Working Paper No. 1. University of Manchester, Global Urban Research Centre.

Newman, P., and J. Kenworthy. 1989. Cities and Automobile Dependence: A Sourcebook. Aldershot: Gower Technical.

Tearfund. 2008. *Linking Climate Change Adaptation and Disaster Risk Reduction.* Teddington: Tearfund.

UN (United Nations). 2010. *World Urbanization Prospects: 2009 Revision.* New York: UN Department of Social and Economic Affairs.

UN-HABITAT. 2007. *Enhancing Urban Safety and Security: Global Report on Human Settlements 2007.* London: Earthscan Publications.

U.S. Conference of Mayors. 2010. "Mayors Leading the Way on Climate Protection." http://www.usmayors.org/climateprotection/revised/.

World Bank. 2009. *World Development Report 2009: Reshaping Economic Geography.* Washington, DC: World Bank.

———. 2010a. *World Development Report 2010: Development and Climate Change.* Washington, DC: World Bank.

———. 2010b. *The Economics of Adaptation to Climate Change. Final Synthesis Report.* Washington, DC: World Bank.

List of Authors and their Affiliations

CHAPTER 1
Patricia McCarney, Director, Global City Indicators Facility, University of Toronto

CHAPTER 2
Marina Alberti, Director, Interdisciplinary Ph.D. Program in Urban Design and Planning and the Urban Ecology Research Laboratory, University of Washington

Lucy R. Hutyra, Assistant Professor, Department of Geography & Environment, Boston University

CHAPTER 3
Rajat Gupta, Professor of Sustainable Architecture and Climate Change, School of Architecture, Faculty of Technology, Design and Environment, Oxford Brookes University

Smita Chandiwala, Research Fellow, Oxford Brookes University

CHAPTER 4
Lily Parshall, PhD, School of International and Public Affairs, Columbia University

Stephen A. Hammer, PhD, Director, Urban Energy Program, Columbia University

Kevin Robert Gurney, PhD, Associate Professor, School of Life Sciences, Arizona State University

CHAPTER 5
Julien Bouyer, PhD candidate, CERMA — Ecole Nationale Supérieure d'Architecture de Nantes, France

Marjorie Musy, PhD, researcher, CERMA — Ecole Nationale Supérieure d'Architecture de Nantes, France

Yuan Huang, PhD candidate, CERMA / GARC, School of Architecture and Urban Planning, HUST, Wuhan, CHINA

Khaled Athamena, PHD candidate, LHEEA — Ecole Centrale de Nantes / CSTB Nantes, France

CHAPTER 6
Shagun Mehrotra, Faculty Fellow and Managing Director, Climate and Cities, Columbia University and NASA, Goddard Institute for Space Studies (GISS)

Claudia E. Natenzon, Instituto de Geografía, Facultad de Filosofía y Letras, Universidad de Buenos Aires, and FLACSO Argentina

Ademola Omojola, Associate Professor, Department of Geography, University of Lagos

Regina Folorunsho, Assistant Director, Nigerian Institute for Oceanography and Marine Research

Joseph Gilbride, Project Manager, Climate and Cities, Columbia University and NASA GISS

Cynthia Rosenzweig, Senior Research Scientist and Head, Climate Impacts Group, NASA GISS, and co Chair Climate and Cities, Columbia University and NASA GISS

CHAPTER 7
Christopher Kennedy, Associate Professor, Department of Civil Engineering at the University of Toronto, Canada

David Bristow, Ph.D. candidate, Department of Civil Engineering at the University of Toronto, Canada

Sybil Derrible, Ph.D. candidate, Department of Civil Engineering at the University of Toronto, Canada

E. Mohareb, Ph.D. candidate, Department of Civil Engineering at the University of Toronto, Canada

S. Saneinejad, MASc candidate, Department of Civil Engineering at the University of Toronto, Canada

R.Stupka, MASc candidate, Department of Civil Engineering at the University of Toronto, Canada

L. Sugar, MASc candidate, Department of Civil Engineering at the University of Toronto, Canada

R. Zizzo, MASc candidate, Department of Civil Engineering at the University of Toronto, Canada

B. McIntyre, Manager Community Transformation, Toronto and Region Conservation Authority

CHAPTER 8
Andy van den Dobbelsteen, Professor of Climate Design & Sustainability, Faculty of Architecture, Delft University of Technology

Nico Tillie, PhD Candidate, Faculty of Architecture, Delft University of Technology

Marc Joubert, Joubert Architecture, Rotterdam

Wim de Jager, Gemeentewerken, City of Rotterdam

Duzan Doepel, Doepel Strijkers Architects, Rotterdam

CHAPTER 9
István László Bart, EU Emissions Trading Scheme, European Commission Directorate-General Environment

CHAPTER 10
Robert Clavel, Project Manager, Centre d'études sur les réseaux, les transports, l'urbanisme et les constructions (Certu), Ministère de l'Écologie, du Développement et de l'Aménagement durables, Lyon, France

Elodie Castex, PhD Candidate, Geography, Université d'Avignon et des pays du Vaucluse

Didier Josselin, Researcher, UMR ESPACE, CNRS, Université d'Avignon et des pays du Vaucluse

CHAPTER 11
Jun Li, Ecole des Mines de Paris, France

CHAPTER 12
John-Felix Akinbami, Associate Professor, Division of Energy Technology and Management, Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria

Akinloye Lawal, Building Department, Joseph Ayo Babalola University, Ikeji-Arakeji, Nigeria

CHAPTER 13
Marco Schmidt, Institute of Architecture, Technische Universität Berlin, Germany

CHAPTER 14
Tristan Kershaw, PhD, Associate Research Fellow, Centre for Energy and the Environment, School of Physics, Exeter University

David Coley, PhD, Senior Research Fellow, Centre for Energy and the Environment, School of Physics, Exeter University

CHAPTER 15
Aumnad Phdungsilp, Lecturer, Faculty of Engineering, Dhurakij Pundit University, Bangkok, Thailand

CHAPTER 16
Roberto Sanchez Rodriguez, University of California, Riverside, USA

CHAPTER 17
JoAnn Carmin, Associate Professor of Environmental Policy and Planning, Department of Urban Studies and Planning, Massachusetts Institute of Technology

Debra Roberts, eThekwini Municipality, Durban, South Africa

Isabelle Anguelovski, Marie Curie Postdoctoral Fellown, Institute for Environmental Science and Technology, Universitat Autònoma de Barcelona

CHAPTER 18
Armando Carbonell, Chairman, Department of Planning and Urban Form,

Lincoln Institute of Land Policy, Cambridge, Massachusetts

Douglas J. Meffert, Eugenie Schwartz Professor of River & Coastal Studies and

Deputy Director, Tulane/Xavier Center for Bioenvironmental Research

CHAPTER 19
Christopher Gore, Ph.D., Associate Professor, Politics and Public Administration, Ryerson University, Toronto, Canada

Pamela Robinson, Associate Professor, School of Urban and Regional Planning, Ryerson University, Toronto, Canada

Richard Stren, Professor Emeritus Political Science, and Senior Advisor, Cities Centre University of Toronto

CHAPTER 20
Jennifer Penney, Director of Research, Clean Air Partnership, Toronto, Canada

Thea Dickinson, Researcher, Clean Air Partnership, Toronto, Canada

Eva Ligeti, Executive Director, Clean Air Partnership, Toronto, Canada

CHAPTER 21
Belinda Yuen, Associate Professor, National University of Singapore

Leon Kong, Director, AKO Knowledge Solutions, Singapore

CHAPTER 22
Le-Yin Zhang, Senior Lecturer, Development Planning Unit (DPU), University College London (UCL)

CHAPTER 23
Thierry Paulais, Sr. Urban Finance Specialist, Cities Alliance

Juliana Pigey, Senior Associate, Urban Institute Center on International Development & Governance

CHAPTER 24
Patricia Clarke Annez, Research Director, Making Cities Work for the Growth Agenda Project, Wolfensohn Center, Brookings Institution

Thomas Zuelgaray, Ecole Nationale de Travaux Publics d'Etat of Lyon, France

CHAPTER 25
Jacob Park, Associate Professor, Business Strategy and Sustainability, Green Mountain College, Vermont, USA

CHAPTER 26
Jean Cavailhès, Director of Research, UMR 1041, INRA/AgroSup CESAER, F-21000, Dijon, France

Daniel Joly, Director of Research, CNRS, UMR 6049 ThéMA, F-25000 Besançon, France

Hervé Cardot, Professor, University of Burgundy, IMB, UMR CNRS 5584, F-21000, France

Mohamed Hilal, Research Engineer, UMR 1041, INRA/AgroSup CESAER, F-21000, Dijon, France

Thierry Brossard, Director of Research, CNRS, UMR 6049 ThéMA, F-25000 Besançon, France

Pierre Wavresky, Study Engineer, UMR 1041, INRA/AgroSup CESAER, F-21000, Dijon, France

CHAPTER 27
Sheridan Bartlett, Researcher, International Institute for Environment and Development (IIED)

David Dodman, Researcher, Climate Change and Human Settlements Groups, International Institute for Environment and Development (IIED)

Jorgelina Hardoy, Researcher, International Institute for Environment and Development Latin America (IIED-AL)

David Satterthwaite, International Institute for Environment and Development (IIED)

Cecilia Tacoli, Human Settlements Group and Rural-urban, International Institute for Environment and Development (IIED)

CHAPTER 28
Lucy Winchester, Researcher, Latin American and The Caribbean Institute for Economic and Social Planning, Economic Commission for Latin America and the Caribbean, United Nations

Raquel Szalachman, Economics Affairs Officer, Sustainable Development and Human Settlements Division, Economic Commission for Latin America and Caribbean United Nations

CHAPTER 29
Vilas Nitivattananon, Associate Professor, Urban Environmental Management, School of Environment, Resources and Development, Asian Institute of Technology, Thailand

Tran Thanh Tu, Department of Urban and Environmental Engineering, Graduate School of Engineering, Kyoto University, Japan

Amornrat Rattanapan, Independent Consultant

Jack Asavanant, Faculty of Science, Chulalongkorn University, Thailand

CHAPTER 30
Huraera Jabeen, Senior Lecturer, Department of Architecture, BRAC University, Bangladesh

Adriana Allen, Senior Lecturer at the Development Planning Unit, University College London

Cassidy Johnson, Lecturer, Development Planning Unit, University College London

CHAPTER 31
Jostacio M. Lapitan, Technical Officer, Urbanization and Emergency Preparedness, World Health Organization (WHO), Kobe Centre (WKC)

Pauline Brocard, Technical Officer, Strategic Initiatives Team, The Global Fund to Fight AIDS, Tuberculosis and Malaria Geneva, Switzerland

Rifat Atun, Professor, International Health Management, Imperial College London and Head of the Healthcare Management Group

Chawalit Tantinimitkul, Health Officer, Ministry of Public Health of Thailand

PART 1

Measurement and Indicators of City Climate Impacts and Performance

CHAPTER 1

City Indicators on Climate Change: Implications for Policy Leverage and Governance

Patricia McCarney*

1. Introduction

Risks associated with climate change are increasingly finding expression in cities.

The vulnerability of cities to climate change is largely underestimated. There is no established or standardized set of city indicators that measures the effects of climate change on cities and assesses those risks and the role that cities play for, example, in contributing to greenhouse gas (GHG) emissions. While the literature on urban governance is extensive and the research field of city indicators has grown and strengthened in very recent years, there is little work to date on how city indicators can be utilized for improved governance. It is the intersection of city indicators and city governance that this paper begins to address.

The central research question to be addressed is how indicators on cities and climate change can add new policy leverage for local governments, in terms of building empowered decision-making and, developing evidence-based policy-making.

The objectives of this paper are threefold: first, to map the core risks for cities associated with climate change through literature review and city case studies; second, to examine the use of city indicators to assess and address these risks

Corresponding author: Patricia.McCarney@daniels.utoronto.ca

and vulnerabilities in cities; and third, to determine how knowledge derived from city indicators on climate change can help to direct a more informed set of planning norms and practices, more effective infrastructure investment and urban management, and a more inclusive urban governance.

In addition, this paper will identify gaps in city indicators and/or weaknesses in methodologies for comparative indicators on cities and climate change and new challenges in the emerging field of cities and climate change. New governance challenges for cities that arise as a result of new risks and vulnerabilities associated with climate change will also be identified.

2. Mapping Climate Change Risks in Cities: Core Risks and Urban Vulnerabilities

While assessment on climate change and risks to cities is quite diverse and varied, for the purposes of this paper, four broad categories are identified for considering urban vulnerabilities associated with climate change: alterations in temperature, alterations in precipitation, alterations in storm intensity and sea level change. The first three, associated with extreme weather events and the fourth, associated with sea level change are not well measured as discrete phenomenon in terms of cities. A further problem that emerged from the literature review on climate change is the coupling of natural disasters with climate change recordings. Global increases in those natural disasters specifically associated with climate change are not well disaggregated. Natural disasters associated with climate change can be identified as having direct consequences for cities, but again these measures are not disaggregated. We also know, both through informed professionals and broad ratings that poorer urban households are usually at higher risk due to weaker structures, less safe city locations and building sites, and weaker resilience of infrastructure in poorer cities to withstand damage

Cities in developing countries are disproportionately affected for similar reasons of vulnerability and weak institutional support and infrastructure systems. Creating measures and indicators across the spectrum of vulnerabilities is required for informed decision-making, improved policy on climate resiliency in cities, more effective urban management of risks, and more empowered governance at the city level.

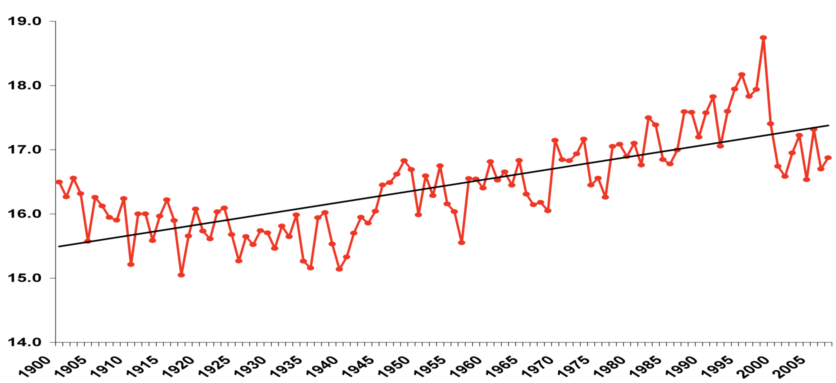
2.1.1 Assessing Urban Vulnerabilities Associated with Climate Change

Category One — Alterations in Temperature

The urban vulnerabilities associated with *alterations in temperature* include warmer and more frequent hot days and nights in cities and more extreme events such as heat waves, producing increased demand for cooling, declining air quality in cities, energy shortages, heat island effects, increased water demand and water quality problems, human health effects and increased risk of heat-related mortality. These consequences are detailed in Table 1. Each of these vulnerabilities helps to identify specific measurement needs and core indicators for assessing urban vulnerabilities associated with alterations in temperature. First, an assessment is made of what city level measures already exist and a sampling of cities already doing work on temperature change in their cities so as to better identify weaknesses in measurement and gaps in current information.

Current global data informs a substantial change in global mean temperatures over the last 100 years. Global temperatures have increased by 0.74°C, which is unusual in comparison to changes in global temperature data in the past (IPCC 2007). Not surprisingly, increases in global temperature affect temperature trends in cities. For example, and as indicated in Graph 1, the average temperature in Mexico City has been steadily increasing over the past century, and particularly since about 1960.

FIGURE 1
Temperature Average in Mexico City 1900-2007
Temperature (°C)



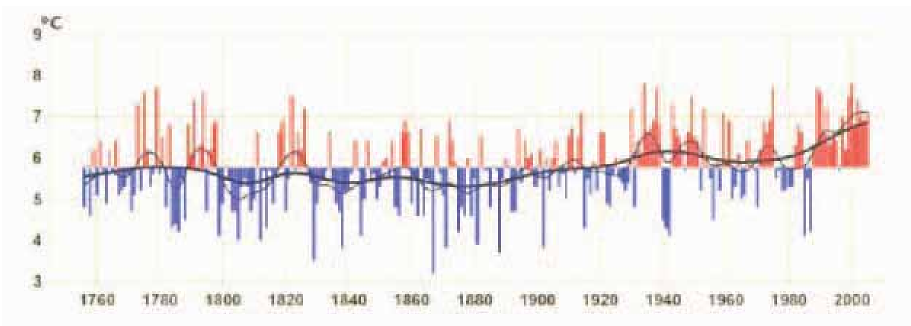
Source: Secretaria del Medio Ambiente del Distrito Federal, 2008. Mexico City Climate Action Program 2008-2012.

In addition, cities at their core tend to be 1 to 10°F (0.56 to 5.6°C) warmer than their surrounding suburbs and rural areas (*Science Daily 2003).* This is attributed to urban heat island effects caused by extensive paving, high densities of buildings and minimal green space and fauna in city cores. Temperature change is also indicated by a heightened frequency and intensity of heat waves, resulting in an increased number of heat related deaths. The 2003 heat wave in European cities was responsible for 35,000 to 50,000 deaths.

High temperatures in urban areas have a direct effect on the energy consumed by cooling appliances such as air conditioners. In large cities in the United States, the peak electricity load increases 3 to 5 percent for 1°C increase in temperature. This is significant, considering that the average afternoon summer temperature in U.S. cities has increased by 1.1°C in the last 40 years.

Graph 2 indicates the rise of temperatures in Stockholm, particularly since 1970. Also since 1985, the graph indicates the diminishing number of cold days in Stockholm being replaced by an increasing number of hot days.

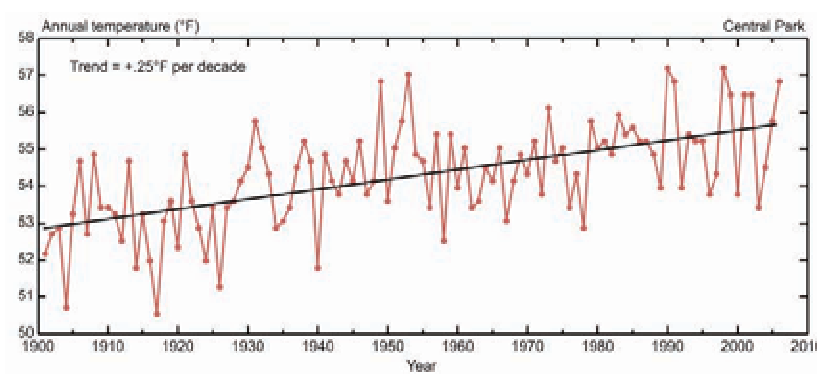
FIGURE 2
Reconstructed Mean Annual Temperatures in Stockholm 1756 - 2000



Source: The City of Stockholm 2007. Adapting to Climate change in Stockholm

Alterations in temperature have also been tracked in New York City. Graph 3 indicates a trend in temperature rise of over .25°F per decade since 1900. New York City has also experienced an increase in number of hot days (over 90°F) since 1980.

FIGURE 3
New York City — Annual Temperature in Central Park, Manhattan 1901-2006



Source: New York City Panel on Climate Change 2009. *Climate Risk Information*.

As indicated in Appendix A, three tables on observed temperature extremes measured in Central Park, Manhattan indicate maximum temperatures exceeding 90°F and 100°F as well as the number of heat waves experienced per year over the past century in New York City. During 1971-2000, New York City averaged 14 days per year over 90 degrees, 0.4 days over 100 degrees, and two heat waves per year. The number of events in a given year is highly variable. For example, in 2002 New York City experienced temperatures of 90 degrees or higher on 33 different days; in 2004 temperatures of 90 or higher only occurred twice. None of the post-1900 trends for these heat events can be distinguished statistically from random variability. However, seven of the ten years with the most days over 90 degrees in the 107-year record have occurred since 1980 (New York City Panel on Climate Change 2009).

2.1.2 Assessing Urban Vulnerabilities Associated with Climate Change *Category Two — Alterations in Precipitation*

With regard to urban vulnerabilities associated with alterations in precipitation, the consequences for governing, planning and managing cities are far-reaching.

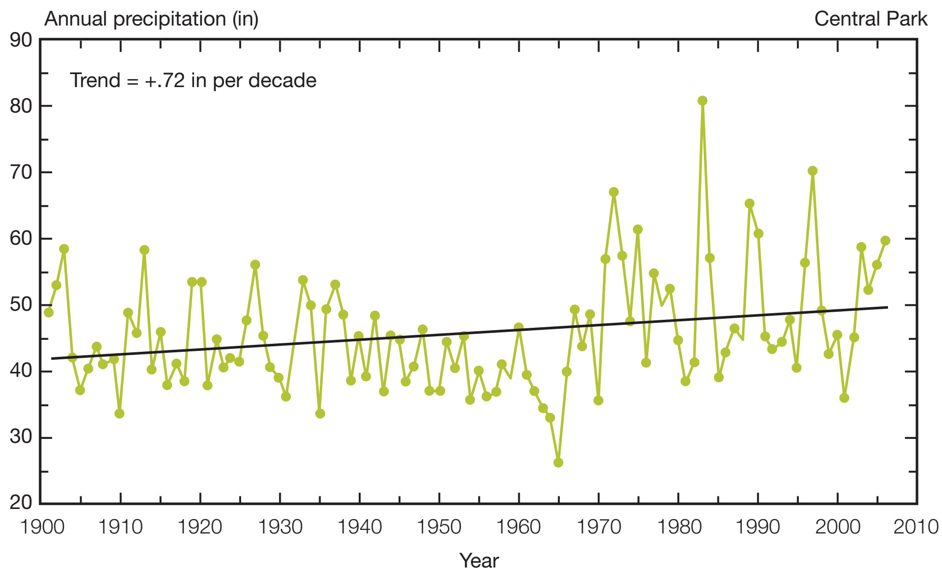
Increasing frequency and intensity of precipitation in cities and more extreme precipitation events can cause pressure on, and deterioration of, water and sanitation infrastructure, particularly for weak and/or aging municipal infrastructure facilities. In addition, these alterations create adverse effects on the quality of surface and groundwater, contaminate water supply, create waterborne diseases, increase risk of deaths, infectious respiratory and skin diseases, disrupt settlements, commerce and transport due to flooding, and, cause large displacements of people together with loss of property.

By contrast, alterations in precipitation leading to drought also lead to adverse effects in cities, such as escalating costs of food in cities, food crises and increased migration into cities from drought affected regions. These consequences are further detailed in Table 1. Each of these ten consequences helps us identify specific measurement needs and core indicators for assessing urban vulnerabilities associated with alterations in precipitation. This framework of vulnerabilities identified assists in first assessing what city level measures already exist across this list of core vulnerabilities and then identifying gaps in current information.

According to IPCC, precipitation has increased over land north of 30 °N where a general decline has occurred over the tropics since the 1970s. Data at the city level is however weak on this measure since national (and global) data is not usually disaggregated by city and only some cities gather information on precipitation.

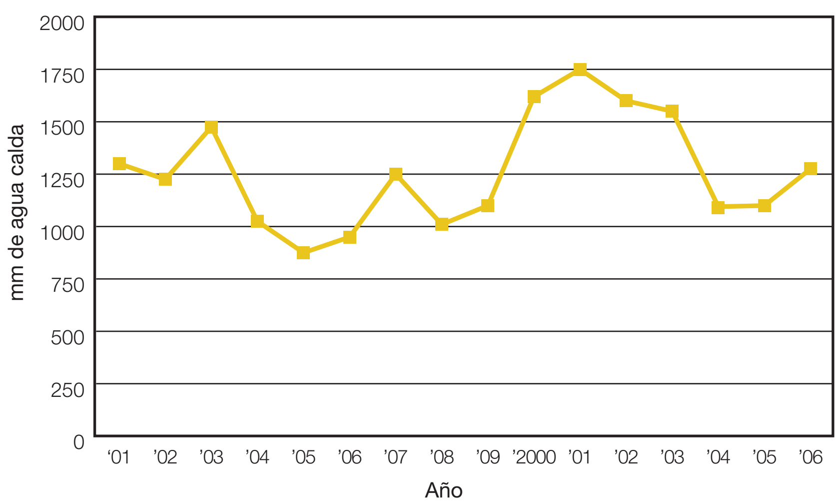
New York City (Graph 4) and Buenos Aires (Graph 5) are two examples of cities that gather data on alterations in precipitation. According to this data, there has been a gradual increase in annual precipitation in the case of New York City over the past 100 years. Alteration in precipitation recorded in Buenos Aires between 1991 and 2006 has been sporadic with some upward trend indicated over this shorter time period.

FIGURE 4
Annual Precipitation in New York City



Source: New York City Panel on Climate Change 2009. *Climate Risk Information.*

FIGURE 5
Precipitation in Buenos Aires 1991-2006

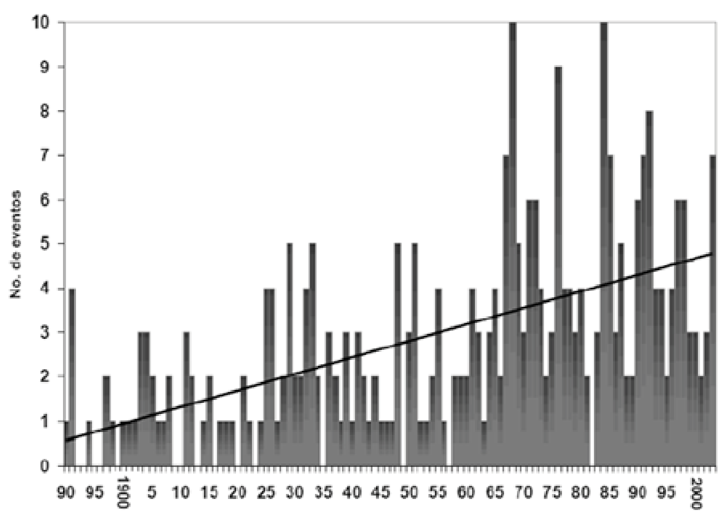


Source: Agencia de Protección Ambiental, Gobierno de la Ciudad de Buenos Aires 2008. *Plan Estratrégico 2008-2012*. Precipitaciones Registradas en la Ciudad Autonoma de Buenos Aires (1991-2006).

Where local data does exist, heavy precipitation can be seen as creating serious consequences for cities in terms of flooding, economic stress and increased health risks. For example, the E-Coli contamination in Walkerton, Ontario in 2000 was a result of excess runoff from overwhelmed sewer systems (Henstra and McBean 2003). Flooding from heavy precipitation causes infrastructural damages and economic loss due to the disruption of daily operations in cities. The 1996 flooding in the Saguenay Region of Quebec due to heavy rainfall resulted in the evacuation of 15,000 people and caused losses of over $1.5 billion Canadian (Henstra and McBean 2003).

Occurrences of heavy precipitation events are not recorded by many cities globally despite the serious consequences known to result. Mexico City however has more than a century of data recorded on the number of extreme precipitation events. As seen in Graph 6, these recordings indicate a marked increase, especially since 1965.

FIGURE 6
Number of Extreme Precipitation Events (>30mm/day) in Mexico City 1890-2003



Source: Secretaria del Medio Ambiente del Distrito Federal 2008. *Mexico City Climate Action Program 2008-2012.*

Alterations in precipitation associated with drought in many regions also directly impact cities by creating food shortages, causing food prices to rise and leading to potential food crises in cities worldwide. Cities particularly affected by the recent global food crisis include Port-au-Prince, Dhaka, Cairo, Douala, Manila, Jakarta, and major cities in Burkina Faso and Yemen. The global food crisis brought on by drought has been the source of urban violence in many cities, manifested in a series of city riots. For example, the riot in Port-au-Prince which shut down the city in April 2008, was a result of tensions arising from the global food crisis. At least ten people were killed from the riots in Cairo, which were due to shortages in basic food commodities and rising food prices.

Lowered precipitation levels also lead to increases in migration into cities from climate change affected areas. Water shortages in cities are also a consequence of alterations in precipitation linked to climate change that pose serious risks for the general urban population and particularly for the more vulnerable groups such as the elderly, the young and the chronically sick.

2.1.3 Assessing Urban Vulnerabilities Associated with Climate Change *Category Three — Alterations in Storm Frequency and Intensity*

The consequences of alterations in storm frequency and intensity –for cities include power outages and disruption to the public water supply; disruptions to settlements associated with flood and high winds; migration of population under stress; loss of property; withdrawal of risk coverage or cost escalation of insurance by private insurers; and more generally, increased risks of deaths, injuries, and water and food-borne diseases and post-traumatic stress disorders. These seven consequences are detailed in Table 1. While global and national data on storms is being generated, city level measures assessing these vulnerabilities are not yet well formulated. Categorizing these vulnerabilities helps us identify specific measurement needs and core indicators for assessing urban vulnerabilities associated with alterations in storm frequency and intensity.

One measure of Atlantic tropical cyclones shows the average number of storms increasing over the period from 1900 to 2005, from an annual average of six storms in the period 1930 to 1940, to an annual average of 15 storms from 1995 to 2005 (National Center for Atmospheric Research 2007).

Three major storms that directly affected cities since the year 2000, all demonstrated the consequences detailed in Table 1, namely, settlement disruption, loss of property and mortality. In Mozambique in 2000, for example, the storm consequences in Maputo and other cities included loss of property, 700 deaths and settlement disruption to 4.5 million people. In Germany and other neighbouring countries, flooding along the Elbe and Danube Rivers caused damage to Dresden and other cities in 2002. Mortality reached 90 and 30,000 people were evacuated from the City of Dresden. In the United States, the largest storm disaster in US history occurred in the City of New Orleans in 2005 with deaths reaching 1,863 and economic losses measured at $US81.2 billion.

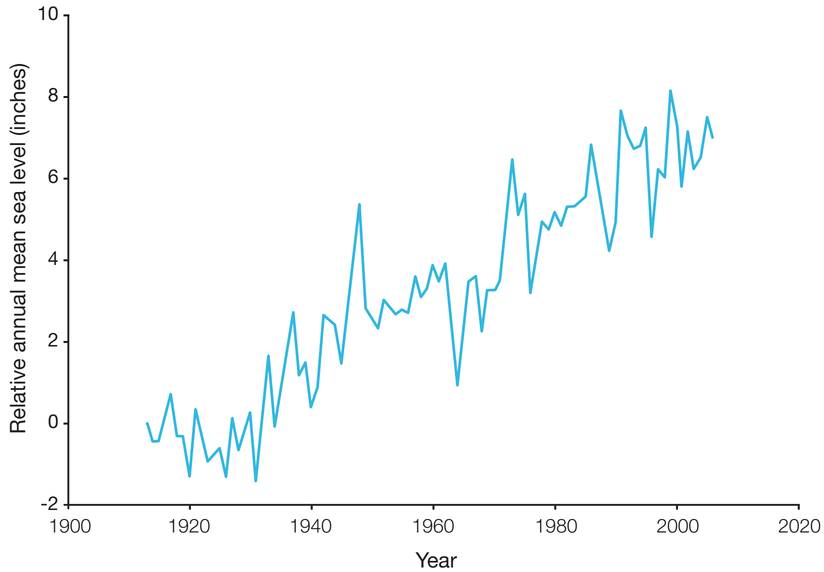
2.1.4 Assessing Urban Vulnerabilities Associated with Climate Change
Category Four — Sea Level Change

Key consequences associated with sea level change include permanent erosion and submersion of urban land and settlements; loss of property and livelihood; costs of coastal protection; costs of land-use relocation; decreased freshwater availability due to saltwater intrusion and salinity in estuaries and coastal aquifers; increased risks of deaths and injuries by drowning in floods; rising water tables and impeded drainage; destruction of urban infrastructure; and long-term effects on economic growth. These nine consequences are detailed in Table 1. Each of these vulnerabilities helps us identify specific measurement needs and core indicators for assessing urban vulnerabilities associated with sea level change. This framework of vulnerabilities can help to direct research towards identifying what city level measures already exist across this list of core vulnerabilities and then identifying gaps in our current information.

Climate change research in general has tended to focus on coastal cities and a gap has been identified in research on inland cities (Hunt and Watkiss 2007). There are 3,351 cities in what are termed Low Elevation Coastal Zones (LECZ) around the world. Many coastal cities are threatened by sea level increases and it is estimated that by 2015, 21 of the world's megacities will be in costal locations (Kreimer et al. 2003). Approximately 17 percent of the total urban population in Asia lives in low elevation coastal zones with 449,845 people at risk from sea level rise. According to IPCC (2007), the rate of sea level rise has increased in the last decade to 3.1 mm/year (compared to 1.8 mm/year for previous years); IPCC also predicted that average sea levels will rise by about 18 centimeters by 2040 and by about 58 centimeters by 2100 in the most extreme case. According to Vermeer and Rahmstorf (2009), global sea levels could rise between 75 to 190 centimeters for the period 1990-2100. The projected rise is about three times as much as that estimated by IPCC (2007), which did not fully include the effects of ice loss from Greenland and Antarctica.

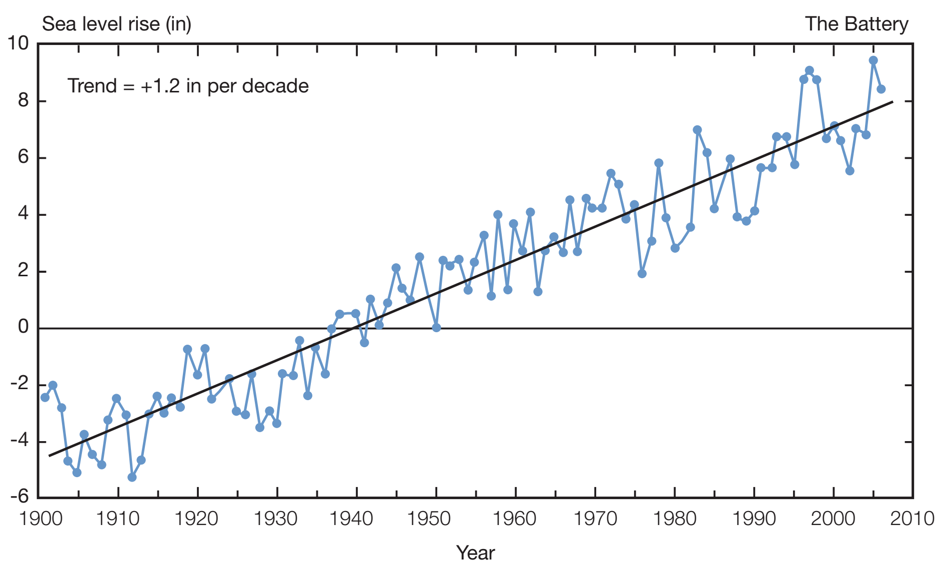
Some cities are tracking sea level changes. But when four cases - Miami, New York City, Vancouver and San Francisco are examined, it was found that sea level change is measured differently in each case. Graphs 7-10 indicate sea level rise in Miami, New York City, Vancouver and San Francisco respectively. These graphs consistently demonstrate increases in sea level in all four cities. A table compiled and presented in Appendix B, presents in more detail the different ways in which sea level change is measured across these four cities. If sound comparisons across cities on the extent of sea level change are to be drawn, then it is important to build standardized methodologies, indicators and measurements to allow for this comparability.

FIGURE 7
Mean Annual Sea Level Rise in Key West, Florida Over Time



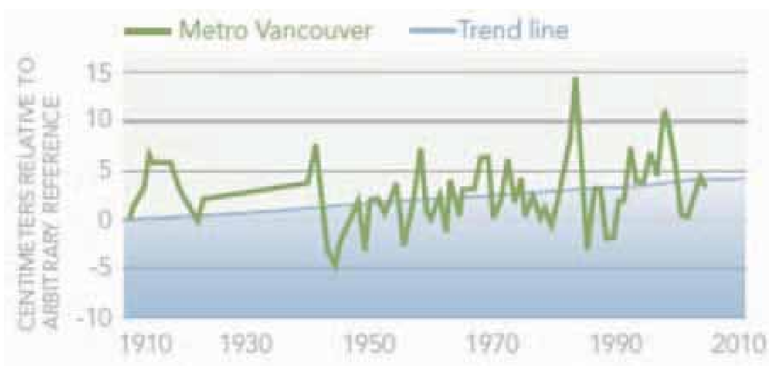
Source: The City of Miami 2008. *MiPlan: City of Miami Climate Action Plan*.

FIGURE 8
Annual Average Sea Level — New York City



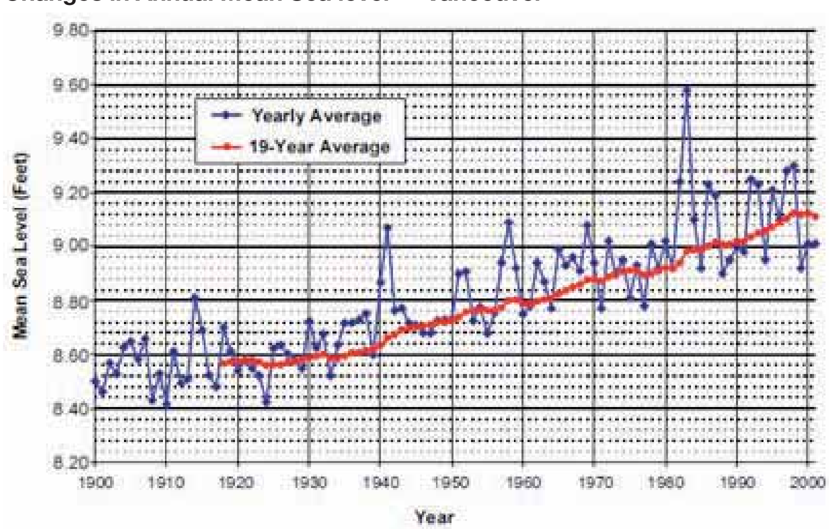
Source: New York City Panel on Climate Change 2009. *Climate Risk Information.*

FIGURE 9
Changes in Annual Mean Sea level — Vancouver



Source: Metro Vancouver 2009. *Metro Vancouver Sustainability Report*.

FIGURE 10
Changes in Annual Mean Sea level — Vancouver



Source: San Francisco Department of the Environment, San Francisco Public Utilities Commission. 2004. *Climate Action Plan for San Francisco: Local Actions to Reduce Greenhouse Gas Emissions.*

TABLE 1
Urban Vulnerabilities Associated with Climate Change

Four Categories of Urban Vulnerabilities	City Impacts
(i) Temperature change	• Heat island effect • Increased demand for cooling and energy shortages • Declining air quality in cities • Reduced disruption to transport due to snow, ice • Increased water demand • Water quality problems • Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated • Reduction in quality of life for people in warm areas without appropriate housing
(ii) Alterations in precipitation • Frequency of increase • Drought	• Adverse effects on quality of surface and groundwater • Contamination of water supply • Waterborne diseases • Poor solid waste disposal • Increased risk of deaths, injuries, and infectious, respiratory, and skin diseases • Disruption of settlements, commerce, transport, and societies due to flooding • Large displacement of people • Pressures on urban and rural infrastructures • Destruction of urban infrastructure • Loss of property • In-migration from climate change affected areas • Food and water shortage • Increased price of food • Increased migration to cities
(iii) Storm activity increase (high winds, cyclones, hurricanes, etc.)	• Power outages • Distress migration to urban areas • Disruption of public water supply • Increased risk of deaths, injuries, water and food-borne diseases; post-traumatic stress disorders • Disruption by flood and high winds\ • Withdrawal of risk coverage in vulnerable areas by private insurers • Potential for population migrations • Loss of property
(iv) Sea level change	• Decreased freshwater availability due to saltwater intrusion • Increased risk of deaths and injuries by drowning in floods and migration-related health effects • Loss of property and livelihood • Permanent erosion and submersion of land • Costs of coastal protection versus costs of land-use relocation • Potential for movement of populations and infrastructure • Increased salinity in estuaries and coastal aquifers • Rising coastal water tables and impeded drainage. • Degraded dykes that are unable to sustain future tides • Encroachment of settlement onto low lying areas • Destruction of urban infrastructure • Effect on long-term economic growth

Source: These four categories of urban vulnerabilities are compiled from both the World Bank's Climate *Resilient Cities Report, 2009* and IPCC's *Climate Change 2007: Synthesis Report 2007.*

City leaders are often not present when international protocols and agreements on climate change are discussed by member states and when states decide on whether to sign and support these international agreements. The vulnerability of cities to climate change risks is largely underestimated. There is no established set of city indicators on climate change that is globally standardized and comparable. With increasing urban vulnerability, estimated simply by the fact of the increasing dominance of city dwellers worldwide, city governments need to be considered as new sites of governance in global negotiations on climate change and in decision-making related to risk assessments.

With national governments increasingly confronting new and emerging global agendas on climate change — and because these agendas all place cities at risk - national governments while negotiating global commitments must also initiate dialogue and consensus at the city level to ensure that local authorities are part of the decision-making, and importantly, as integral parts of mitigation, adaptation and implementation processes.

2.2 Mapping Cities and Climate Change

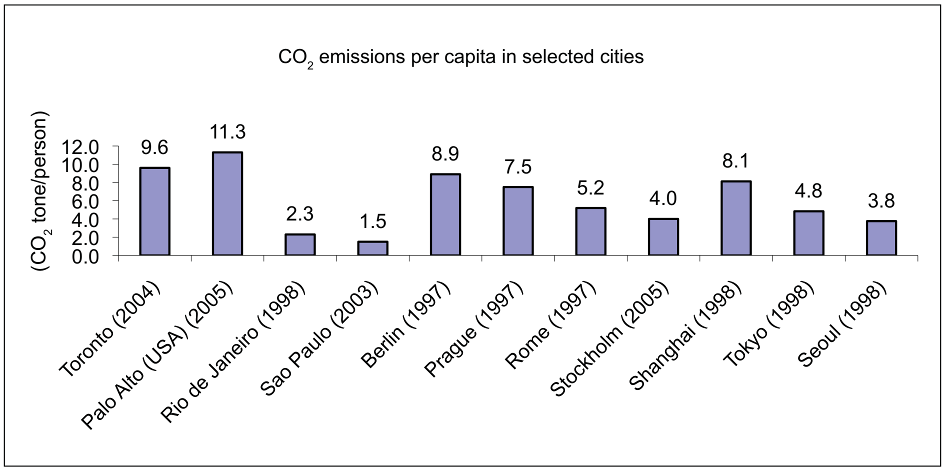
2.2.1 Cities and GHG Emissions

Cites are key actors in carbon emissions that contribute to climate change. . GHG emissions are usually under the control or influence of local governments since a majority of these emissions are linked to urban form that affects transportation and energy consumption. For example, according to a recent calculation by the Province of British Columbia, Canada, 43% of its provincial GHG emissions are under the control of local governments (Cavens et al. 2008)

Cities can make a positive contribution to the climate change agenda by consciously making urban related decisions that are informed by a clear understanding of their contribution to the problem and finding ways to mitigate and adapt to it. However, measurements of emissions by cities are as yet uneven in both development and application that can guide city mitigation strategies.

Several indicators are available to estimate a city's overall GHG emissions. UN-Habitat has presented preliminary information on comparative city emissions (as in Graph 11 below). Building sound comparative measures for cities is a challenge that UN-Habitat, ICLEI, the World Bank, UNEP and many other leaders are currently confronting. The indicator of 'greenhouse gas emissions measured in tons per capita' currently in use by the Global City Indicators Facility (GCIF) at the University of Toronto is based on existing methodologies in current use by IPCC and the methodology adopted in the ICLEI HEAT Software Tool (Harmonized Emissions Analysis Tool). This GCIF indicator measures the total tonnage of GHG (in carbon dioxide equivalent units) generated over the past year by all activities within the city (the numerator) divided by the current city population (the denominator) expressed as a per capita figure. A working group with Global City Indicator Facility and World Bank participation is reviewing this methodology based upon new methodologies and protocols being developed.

FIGURE 11
Greenhouse Gas Emissions by City



Source: UN-HABITAT, *State of the World's Citie, 2008*[8]

A number of different protocols exist for GHG emissions calculations (see Kennedy et al. 2009). ICLEI's Local Government GHG Emissions Analysis Protocol is a two-pronged analysis in which local government emissions are a component of community emissions, together forming a complete GHG emissions inventory. Both the government and community scopes include measures for stationary combustion, mobile combustion, fugitive emissions, product use, other land use and waste. Another protocol developed to calculate GHG emissions for cities (Kennedy et al. 2009) uses seven components: electricity, heating and industrial fuels, direct industrial emissions, ground transportation, air, marine and waste. Air and marine travel represents the main differences between Kennedy et al. (2009) and ICLEI's protocol.

[8]Source for UN-HABITAT chart: Toronto: Greenhouse Gases and Air Pollutants in the City of Toronto ICF International 2007; Palo Alto: Mayor's Green Ribbon Task Force on Climate Protection Final Report — Palo Alto City Council Study Session 12/18/2006; Rio de Janeiro: Inventory of Greenhouse Gas Emissions — City of Rio de Janeiro 2003; Sao Paulo: Inventory of Greenhouse Gas Emissions - City of Sao Paulo 2005; Berlin, Prague and Rome: ICLEI 1997 apub 2003 Inventory Stockholm: Stockholm City Council Web page Shanghai, Tokyo and Seoul: Shobhakar Dhakal, Urban Energy Use and Greenhouse Gas Emissions in Asian Mega-Cities, IGES 2004

Transboundary travel whether commuter travel by road or rail, freight, or air travel are various aspects of a city's porous boundary that make GHG emissions computation complex. At the community level, ICLEI calculates air travel emissions only when air travel originates within the community or serves the needs of the community's residents. At the government level, only employee air travel is included. All other air travel is excluded from ICLEI's calculations because it says it is nearly impossible to determine the boundaries in which the emissions occurred. Some cities, such as the City of Toronto, exclude air travel emissions from GHG calculations altogether. Kennedy et al. (2009) include only airports and marine ports situated within the city limits (Kennedy et al. use the example of London in which Heathrow and City airports are included but Gatwick and Stansted are excluded). A more recent methodology tested by Hillman and Ramaswami (2010) for 8 US cities enables spatial allocation of jet fuel use at large metropolitan airports to surrounding cities. Tested for US cities such as Denver, Seattle, Portland, Minneapolis and Austin, Hillman and Ramaswami (2010) demonstrate that incorporating spatially-allocated freight, commuter and airline fuel use, along with life cycle based GHG emissions associated with producing key urban materials such as food, cement, transportation fuel, that are essential for life in all cities and used in all cities, yields consistency in per capita GHG emissions from the city to the national-scale. Life cycle based embodied GHG associated with key urban materials are recommended to be reported as Scope 3 emissions; consistently accounting for Scope 3 emissions ensures cities do not shift emissions outside boundaries, e.g. in a future hydrogen fuel transport economy. Recent field work in transboundary GHG emissions accounting is yielding important advances toward developing a harmonized protocol for reporting GHG emissions associated with urban activities. A review of various protocols (as of 2009) is provided in Kennedy et al. (2009).

2.2.2 City Mitigation Strategies on Climate Change

With urban areas contributing to more than 70% of global GHG emissions, it is reasonable to understand why cities are becoming the key actors in global mitigation efforts. City governments can influence patterns of energy and land use through important interventions under their control, including land-use planning, urban design, zoning and local by-laws including building codes and height by-laws, transport planning including transit planning road networks, master plan and subdivision controls.

The five sectors identified by Kessler et al. (2009) in Table 2 help to frame points of intervention by cities for climate change mitigation, suggesting available technologies and policy instruments available to cities. A few examples of city action in the field of climate change mitigation can assist in considering measurements for targeting and monitoring mitigation efforts.

TABLE 2
Mitigation Strategies

Sector	Key mitigation technologies and practices currently commercially available	Policies, measures, and instruments shown to be environmentally effective
Energy supply	• Improved supply and distribution efficiency • Fuel switching from coal to gas • Nuclear power • Renewable heat and power (hydropower, solar, wind, geothermal, and bio-energy) • Combined heat and power • Early applications of CO_2 capture and storage (e.g. storage of removed CO_2 from natural gas) • Taxes or carbon charges on fossil fuels • Feed-in tariffs for renewable energy technologies • Renewable energy obligations • Producer subsidies	• Reduction of fossil fuel subsidies • Taxes or carbon charges on fossil fuels • Feed-in tariffs for renewable energy technologies • Renewable energy obligations • Producer subsidies
Transport	• More fuel-efficient vehicles • Hybrid vehicles • Cleaner diesel vehicles • Bio-fuels • Modal shifts from road transport to rail and public transport systems • Non motorized transport (cycling, walking) • Land-use and transport planning.	• Mandatory fuel economy • Bio-fuel blending and CO_2 standards for road transport • Taxes on vehicle purchase, registration, use, motor fuels, and roads • Parking pricing • Mobility influenced needs through land use regulations and infrastructure planning • Investment in attractive public transport facilities and non motorized forms of transport
Buildings	• Efficient lighting and day-lighting • more efficient electrical appliances and heating and cooling devices • improved cook stoves • improved insulation • Passive and active solar design for heating and cooling • Alternative refrigeration fluids • Recovery and recycling of fluorinated gases.	• Appliance standards and labeling • Building codes and certification • Demand-side management programs • Public sector leadership programs, including procurement • Incentives for energy service companies
Industry	• More efficient end-use electrical equipment • Heat and power recovery • Material recycling and substitution • Control of non-CO_2 emissions • Wide array of process specific technologies.	• Provision of benchmark information • Performance standards • Subsidies, tax credits • Tradable permits • Voluntary agreements
Waste	• Landfill methane recovery • Waste incineration with energy recovery • Composting of organic waste • Controlled wastewater treatment • Recycling and waste minimization	• Financial incentives for improved waste and wastewater management • Renewable energy incentives or obligations • Waste management regulations

Source: World Bank, *Climate Resilient Cities 2009*

The Vienna City Council adopted the city's Climate Protection Programme as a framework for its Eco-Business plan,which result, is that the city has reduced its solid waste output by 109,300 tonnes, toxic solid wastes by 1,325 tonnes and carbon dioxide emissions by 42,765 tonnes. This Eco-Business plan has saved a total of 138.7 million KWh of energy and 1, 325,000 cubic meters of drinking water. The Eco-Business plan is also now being implemented in Chennai, India, and Athens, Greece. The City of Calgary, Canada, is achieving significant electricity savings and reducing GHG emissions with the EnviroSmart Retrofit Project. Most of Calgary's residential streetlights are being changed to more energy efficient flathead lenses. Streetlight wattage is being reduced from 200W to 100W on residential local roads and from 250W to 150W on collector roads (United Nations 2008a).

In the building sector, improvements to building codes and certification processes for greener buildings are being adopted by a number of cities. The City of Johannesburg, South Africa has implemented mitigation measures that include retrofitting of council buildings, energy savings in water pump installations, and methane gas recovery. One set of measures already well established is the Leadership in Energy and Environmental Design (LEED) building rating and certification system that ensures a building is environmentally responsible by providing independent, third party verification. LEED certification seeks to ensure that a building project meets the highest green building and performance measures. The average LEED building uses 30% less energy, 30-50% less water and diverts up to 97% of its waste from the landfill (U.S. Environmental Protection Agency 2007).

Mexico City has taken various measures to mitigate the effects of climate change by taking action in the areas of water, energy, transportation and waste to reduce its carbon dioxide emissions. On energy, Mexico City has taken action to secure more sustainable housing and buildings to reduce energy consumption. This includes establishing environmental certification systems for buildings and providing funding for new housing with integrating sustainability criteria. Various energy efficiency programs have been in place to reduce emissions including efficient lighting in buildings, efficient street lighting and promoting solar energy in businesses and government buildings. In regards to the water sector, Mexico City has taken action to reduce emissions from septic systems by constructing sewerage and water treatment services in areas of low methane gas. Some of the actions taken in the transportation sector include an obligatory school transportation system, which will reduce CO_2 emissions by 470,958 tons per year by making students take public transportation to school. Mexico City will also expand its transportation system and the implementation of non-motorized mobility and streetcar corridors as an effort to reduce emissions. In regards to waste management, the government plans on capturing and exploiting the bio-gas emitted from the Bordo Poniente State 4 landfill and eventually installing an electrical power plant which will reduce emissions by 1,400,000 tons annually (Secretaria del Medio Ambiente del Distrito Federal 2008).

Portland, USA has been a key player in adopting strategies to address climate change. In 2000, the Portland Office of Sustainable Development (OSD) launched a program to support the design and development of green buildings in the city. The program offers technical assistance, education and financial incentives, and has so far supported more than 300 local buildings. The City of Portland has taken various measures in order to reduce energy use by using renewable sources and making technological improvements. Technological improvements made by the City has reduced energy use by 80%, for example all traffic signals were converted to highly efficient LED bulbs and by doing so have saved the City almost five million kWh per year and over $500,000 annually in energy and maintenance costs (The City of Portland 2005).

When it comes to establishing GHG reduction targets, cities have an important role to play in helping to determine an equitable distribution of GHG reduction targets, which will help to frame mitigation strategies on climate change. For example, current debates between per capita emissions of inner city residents versus suburban residents, between large city residents versus smaller city residents, and between wealthy cities versus poorer ones or production versus consumer cities raises issues of equity in sharing the burden in meeting reduction targets. Measures are weak and no methodology for determining an equitable distribution of high-level GHG reduction targets has been established. (Cavens, Condon, Kellett and Miller 2008).

While it is generally assumed that suburban residents emit significantly more carbon dioxide than inner city residents, it could thus be concluded that it would be more equitable to require suburban communities to shoulder the largest burdens for reductions. However, indicators on this question are still weak. For example, while some estimate that suburban dwellers produce up to three times more GHGs per capita than inner city dwellers, recent data (Glaeser and Kahn 2008) suggest that this dichotomy is not so simple. They report that indeed while per capita emissions rise as you move away from the urban core of Boston, they level off once you are more than ten miles from downtown. Another exception they have found is with respect to Los Angeles where emissions are actually lower in suburban Los Angeles than they are in the central city of that metropolitan area.

Such issues are complicated further by considering the challenges and opportunities of high-growth versus low-growth communities, as well as questions of per capita versus total reduction targets. In the case of British Columbia, the Province plans to negotiate with local governments with the intention of arriving at an equitable allocation on a municipality by municipality basis.

Finally, a new set of indicators on climate change mitigation are also needed if policy makers are to assess the capacity in communities for GHG reductions and what costs related changes would generate — physically, socially and economically — before they can act. Policy makers need to know, for example, how redesign, urban form and rebuilding of the suburbs might overcome, for example, car dependency (Cavens, Condon, Kellett and Miller 2008).

2.2.3 City Adaptation Strategies on Climate Change

Indicators can help cities understand the problem of climate change and inform city managers and leaders in their role in building resilience to its adverse impacts. A number of adaptation measures to climate change in cities are largely made up of individual choices so knowledge through public education, research and publicly accessible data on indicators can assist citizens towards action. Collective action at the community and municipal level carry potential for appropriate response for climate change adaptation in an urban context.

Adaptation measures can take several forms: actions to reduce vulnerability to climate change; spread risk among a wider population (insurance); eliminate activity or behavior that causes climate change; and move vulnerable populations away from hazards.

UN-Habitat has identified five sectors across which cities can consider climate change adaptation options and strategies. This list acts as a portfolio of potentially appropriate adaptation projects and helps to establish a framework for the development of indicators and measurement on adaptation progress.

Many cities are developing strategic plans for climate adaptation. For example, strategies to adapt New York City to "the unavoidable climate shifts ahead" (The City of New York 2007, 136) are included in PlaNYC 2030. New York City's plan for climate change adaptation focuses on securing the city's existing infrastructure, identifying and protecting flood plain zones and specific at-risk communities, and establishing a citywide strategic planning process with emphasis on tracking emerging climate change data and its potential impacts on the city.

New York City's water, transportation, energy, and waste infrastructure systems are all vulnerable to climate change impacts. Sea level changes combined with storm surges of increasing intensity are potential hazards especially to subterranean facilities and waterfront-situated utilities. Given the range of facility owners and operators, an intergovernmental Climate Change Task Force will coordinate the development of adaptation strategies and guidelines for new infrastructure plans (The City of New York 2007). The case of New York City's climate plan is further detailed in Part III of this paper, together with that of London and other cities.

TABLE 3
Adaptation Strategies

Sector	Adaptation option/strategy	Underlying policy framework
Water	Water storage and conservation techniques; incentives for water conservation; water reuse; water recycling; desalination; increase water use efficiency; public education; flood risk map; public participation flood adaptation and mitigation programs; greater investment in water supply systems; controlled use of urban and rural groundwater.	Urban water policies and integrated water resources management; water-related hazards management; integrating climate change into public policy; policy to control groundwater extraction.
Infrastructure and settlements	Cleaning drainage system and replacement of primary sewer system; encourage infiltration and increasing depression and street detention storage; re-designing structures; relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of wetlands as buffer zone against sea level rise and flooding; protection of existing natural barriers; maintaining defensible space around each building/neighbourhood.	Design standards and codes; regulations; integrate climate change considerations into design; land use policies; insurance; financial incentives; public education regarding risk of living in hazard prone areas.
Human health	Heat-health action plans; emergency medical services; access to public 'cooling centers'; improved climate sensitive disease surveillance and control; access to safe water and improved sanitation; greater intergovernmental coordination and cross-boundary coordination	Public health policies that recognize climate risk; strengthened health services; intergovernmental, regional and international cooperation; greater investment in health services.
Urban Transport	Environmentally friendly transport system; energy efficient cars; car pooling; efficient public transportation system; new design standards and planning for urban roads, rail, etc., to cope with warming and drainage; fuel substitution.	Integrating climate change considerations into national transport policy; investment in R&D; incentives for energy efficient car industry.
Energy	Strengthening of overhead transmission and distribution lines; underground cabling for utilities; increasing energy efficiency; emphasis on renewable resources.	Sustainable urban energy policies; regulations; fiscal and financial incentives to encourage use of green energy and building; incorporate climate change in design standards and codes.

Source: UN-HABITAT, *State of the World's Cities 2008*

2.3 Using Indicators to Assess and Address Deeper and Enduring Risks and Long-Term Vulnerabilities in Cities

In 2000, the Millennium Development Goals (MDGs) were adopted by all 191 UN member states, registering a commitment by the international community to development of the poorest regions of the world and to assist the most vulnerable. Central to the MDGs are its eight goals, each with a set of quantitative targets and indicators to ensure a common assessment, and track progress at global, national and local levels towards achievement of the MDGs.

All eight MDGs can be directly connected to the theme of vulnerability in the world's cities. Each of the eight goals finds expression in cities as they relate to poverty, education, gender, child mortality, maternal health, diseases, environment and global partnerships. In addition, meeting the timeframe and the numerical targets of the MDGs will require a determined focus on cities since the majority of affected women, men and children will be living in urban and peri-urban areas by the target dates of 2015 and 2020.

For example, Goal 7 to "Ensure Environmental Sustainability" sets out three targets: to reverse the loss of environmental resources; improve access to safe drinking water; and, improve the lives of slum dwellers. Linking these three targets helps to frame the challenges cities face in addressing climate change in a context of poverty.

The MDG goals and targets are a call to action to assist people living in the most depressed conditions in the world's cities. According to UN-HABITAT, roughly 80% of urban residents in the lowest-income countries already living in slum conditions and based upon projected demographic trends, slum dwellers are expected to double by 2030.

UN-HABITAT's identification of five conditions characteristic of slums, is helping to establish the number of slum dwellers in the world, and a set of indicators to monitor progress towards the goal of improving the lives of slum dwellers:

- Insecure residential status
- Inadequate access to safe water
- Inadequate access to sanitation
- Poor structural quality of housing
- Overcrowding

Risks associated with each of these conditions are critical factors in the foregoing discussion on urban risks associated with climate change across the four categories identified in the foregoing. The situation of poverty in cities worldwide, but in particular in the less developed regions, must be recognized as a core factor in addressing climate change and building more climate resilient cities. This means explicitly recognizing that climate change adaptation must reduce the vulnerability of the poor in cities. To do so however depends on meaningful data on city slums and indicators that track density; water and sanitation infrastructure inadequacies relative to climate change risks, particular alterations in precipitation and sea level change; and, structural qualities of housing at increased risk from alterations in storm intensity and temperature change.

3. CITIES AT RISK: EMERGING APPROACHES TO SAFER CITIES

3.1 From Indicators to Governance — Evidence Based Policy Formulation

The World Bank defines indicators as performance measures that aggregate information into a usable form. Indicators provide a useful tool in the prospective sense for policy making and also in the retrospective sense for assessing policy implementation. Indicators offer assistance to policy-makers by aiding in comparison, evaluation and prediction.

Indicators are important as they help inform policy makers by allowing them to track the problem and provide linkages that are often crowded by statistics (University of Manchester, 2006). Unlike statistics, indicators are often referred to as vehicles for understanding as they inform and explain complex socio-economic phenomena. They are statistical manipulations that provide the public with a clear picture of the problem at large. Indicators have many different purposes and it is important to evaluate indicators in respect to the job they are devised for. Indicators need to be made relevant to climate change and cities so as to constitute a useful tool for local policy makers. However, indicators, as statistical manipulations, can become increasingly problematic when complexity of the measures heightens. This holds true for indicators on climate change. The more complex the indicator, the higher the potential for statistical value being lost (University of Manchester 2008).

Evidence-based policy making is made possible by advances in information technologies. Data driven decision-making in the government domain via quantitative performance metrics can serve to measure implementation success rates, steer investments and refine policy choices.

Environmental performance measures have improved in recent years and empirical approaches to global sustainability are being strengthened. The Environmental Performance Index (EPI) developed by the Yale Center for Environmental Law and Policy at Yale University and the Center for International Science Information Network at Columbia University has developed 25 indicators across six policy categories that quantitatively measures country-scale performance on a core set of environmental policy goals.

While country-level data and analysis on climate change have improved in recent years, serious gaps exist at the city level however. Quantitative city data on climate change is being developed by cities in some discreet form and often adapted from broadly accepted national level methods. Serious gaps and the lack of time series data on cities and climate change hamper efforts to diagnose emerging risks and problems, to assess policy options in terms of both mitigation and adaption strategies, and to gauge the effectiveness of their city-level programs.

The use of proximity-to-target methodology that quantitatively measures city-scale performance against a core set of goals, while useful in theory for measuring the distance between a city's targets and current results, and providing an empirical foundation for policy benchmarking and a context for evaluating city performance, is as yet under-developed for climate change indicators at the city level. Nonetheless, it provides a powerful tool for steering policy and assessing planning and investments in city management.

City indicators also have the potential to exert peer pressure among member cities to perform better (Hezri and Dovers 2006, p9) and also build in global learning potential. When indicators are "developed and shared across a network of actors, indicators have a communicative function, enlightening and informing the worldviews and values of developers and users" (p 13).

Globally comparative indicator-based knowledge on cities and climate change has become increasingly important as national measures evolve and country-level policy positions emerge. City-level indicators that have a globally standardized methodology are important, not for purposes of numerical ranking of cities, but for informing policy decision-making through comparative city data that provides policy leverage for city leaders locally, nationally and globally. The World Bank's Global City Indicators Program provides a system for cities to use globally standardized indicators as a tool for informing policy making through the use of international comparisons. For example, the Secretariat of Finance in Bogota uses indicators from the Global City Indicators Program as a way to track the city's investments and to compare their city's performance relative to other international cities. By using indicators and drawing global comparisons, the Secretariat of Finance "is able to evaluate and monitor performance on their investments and to benchmark their performance in comparison to other cities." (City of Bogota - Finance Secretary 2009[1]).

Global comparisons allow for sharing of best practices. Comparative reports generated from the Global City Indicators Facility website provides a useful tool for Bogota to view and analyze how other cities in Colombia are performing relative to their investments. For example, Bogota has 232 sworn police officers per 100,000 populations while Cali has 248. Nevertheless, there are 19.6 homicides per 100,000 population in Bogota while Cali's figure is around 69.8.

Indicators and reports generated from the Global City Indicators Facility website are used by Bogota's Secretariat of Finance in negotiations "to inform effective evidence-based policy making. Indicators can provide evidence on how well the city is performing in terms of city services and where to allocate investments. During budget negotiations with other Secretariats having information on how other cities provide services and their results has proven to be useful to try to better allocate resources. For example, health absorbs 23% of

[1] Interview and case study material gathered from City of Bogota — Finance Secretary, 2009

the investment budget in the city and even though results are starting to show up it doesn't seem to be enough for the needs of the population — especially when compared with other cities performance. Therefore, it is clear that we need to monitor the investment and analyze where we can improve the process of providing healthcare" (City of Bogota — Finance Secretary 2009[2]).

The importance of globally standardized city indicators for international city comparisons is underlined by the City of Bogota: "Every year the Secretariat of Finance publishes as part of its budget, a document that contains the results for each sector along with the target for the following year. The Global City Indicators allow us to use other cities as benchmarks in measuring our performance" (City of Bogota - Finance Secretary 2009[3])

Policy-resonant indicators, those that "strike a chord with the intended audience," improve the accountability and efficiency of local policy processes by building stakeholders', public, and community understanding of issues and their solutions. Indicator systems pool enormous amounts of previously inaccessible data, making possible long-term trend monitoring that is important for governments to prioritize actions (Hezri and Dovers 2006).

As informational policy instruments, indicators provide more and better knowledge to local decision-makers and offer a evidence-based system of informing decisions. For example, the City of Sao Paulo, a pilot city of the Global City Indicators Program, recognizes the need for indicators as a tool for increasing transparency and accountability within their government. Sao Paulo is an important demonstration of how municipal governments can use indicators to enhance governance and institute evidence-based policy development in the City (City of Sao Paulo 2009[4]). They report "the media and civil society are often skeptical of government statistics. As an active member in this global initiative supported by universities and international organizations, the government of Sao Paulo is hoping to regain legitimacy and public confidence in government statistics by creating more transparency on its performance in city services and on improving quality of life. The Government of Sao Paulo recognizes the growing importance of indicators for planning, evaluating and monitoring municipal services. In addition, use of indicators to assist with public policy making in Sao Paulo has opened more effective dialogue between civil society and the local government" (City of Sao Paulo 2009[5]).

The City of Sao Paulo has recently prepared its Plan – "Agenda 2012" and state that the plan preparation is "a concrete example of how indicators improve governance, establish evidence-based policy making and promote civic engagement." This Agenda derives from a civil society law proposal approved by the City

---

[2]Interview and case study material gathered from City of Bogota — Finance Secretary, 2009

[3]Interview and case study material gathered from City of Bogota — Finance Secretary, 2009

[4]Interview and case study material gathered from City of Sao Paulo, 2009

[5]Interview and case study material gathered from City of Sao Paulo, 2009

Council in 2007, which establishes that all elected mayors must present goals and targets for its administration 90 days after its opening. This document must be based on the proposals of electoral campaign, and is an instrument that compels the municipality to make a public commitment to quantitative targets and goals. The 2012 Agenda identifies priorities, goals and presents 223 targets organized in six different directions: a social rights city; a sustainable city; a creative city; an opportunity city; an efficient city and an equal city. Also, the municipality must report its results periodically and at least every six months. In this sense, the global city indicators that the City of Sao Paulo collects as part of the Global City Indicators Program allows the City to measure performance, impacts and policy effectiveness (City of Sao Paulo 2009[6]).

When indicators are well developed and soundly articulated, they can also influence how issues are constructed in the public realm. This is an important lesson related to cities and climate change since information can help to direct behavior in building climate action. Behavioral change can result from publicly accessible information by becoming embedded in the thought and practices, and institutions of users (Innes1998). Hezri and Dovers (2006) argue for example that "as a source of policy change, learning is dependent on the presence of appropriate information with the capacity to change society's behavior" (p 11) and "community indicator programs or state-of-the environment reporting are usually aimed at influencing the social construction of the policy problem" (p 12).

In addition, in a review on urban sustainability indicators, Mega and Pedersen (1998) suggest that indicators should aid in decision-making at various levels to promote local information, empowerment and democracy. They should also contribute to making the city's process of decision-making more visible and transparent. City indicators can be an important instrument for fostering citizen participation. Information provided by city indicators can improve the effectiveness of active citizen involvement in decision-making and policy development.

City indicators on climate change can therefore enhance understanding of the risks associated with climate change, influence opinion and behavior, shape policy, determine priorities, and thereby evaluate how cities contribute to, and are impacted by global climate change.

3.2 The Role of City Indicators on Climate Change for Effective Planning and Management

When local government is recognized as a legitimate tier in the governance structure of a country, and when financial powers to raise revenues and responsibilities to deliver services are commensurate with the growth and expansion of cities, then the planning and management functions in cities take on meaning,

[6]Interview and case study material gathered from City of Sao Paulo, 2009

and develop influence. Cities worldwide are entering into renewed dialogues with provincial and national governments to discuss this urban agenda. In this context, more rigorous data-driven policy analysis by cities means leverage in intergovernmental relations. Moreover, indicators can help to build more effective planning and efficient management for climate action in cities.

Indicators on climate change at the city level can inform city officials and support their existing, and indeed potentially far-reaching powers of planning, aimed at climate change adaptation and mitigation. As examples, cities have the power to pass legislation related to greenhouse gas emissions; to encourage participation and engage with related governmental agencies and local corporate organizations on climate change mitigation; to build more inclusive institutions in cities for achieving environmental objectives; to plan and design transportation systems that support access by all citizens and rational choices on where to live and work that is in keeping with a climate change agenda for the city; to ensure strong and robust local economic development patterns that build economic opportunity for all citizens while addressing climate change; to address land tenure and land rights in the city and can thereby adopt a pro-poor set of policies governing access to and environmentally safe use of land in the city; to refine building codes, zoning by-laws and to adopt flexible standards governing safer construction of housing, buildings and infrastructure that are more resilient to climate change risk; to adopt standards on greener buildings and sustainable urban infrastructures; and to develop creative financing tools for mobilizing investments that help to overcome climate-related threats derived from a lack of basic infrastructure and environmental amenities for all, and especially the poorest urban residents in cities.

While the planning profession and the planning tools to address safer cities exist, up-front resource commitments in both plan preparation and implementation are scarce in many cities. Climate change action plans, as indicated elsewhere in this paper, are often costly. The Chicago Climate Action Plan reveals the importance of securing a range of sustainable funding sources where a total of US$2,789,000 was contributed by 14 sources from a variety of non-profit foundations, funds, trusts and initiatives as well as pro bono services, Illinois and Chicago government departments, and regional councils (Parzen 2008, 3).

Moreover, there is an information crisis that seriously undermines effective urban planning on climate action. The lack of monitoring structures and standardized city indicators weakens the power of good planning decisions in cities, particularly cities of the developing world concerned with reducing vulnerability to climate change.

The issue of access to land, housing and security of tenure in poorer cities is a critical challenge for climate action. In cities with large urban poor populations, security of tenure is generally acknowledged as the critical first step in the social and spatial integration of slums and low-income settlements. When tenure is in question, slum improvement is politically complex, both for city planners and for residents. Any intervention on the part of government to take action on climate risks, for example in infrastructure upgrading, drainage investments in low-lying areas, improving standards of housing construction and sanitation services, is perceived as a *de facto* recognition of legal status and any improvements by residents themselves are regarded as high-risk investments owing to the lack of property rights and the threat of eviction without compensation. Hence, in considering effective planning and management for climate change action in this context, the overarching land policy and legal climate in the city is paramount. Pro-poor enabling legislation and land regularization instruments are critical components of a city's agenda on climate change.

The rise in extreme weather events associated with climate change places major cities, particularly those located in coastal areas, in particularly vulnerable conditions. Global increases in natural disasters associated with climate change have shown that the nature of disasters in cities have becomes more multifaceted, and so must the approach to their management. These emerging climate change risks create new vulnerabilities for cities. Urban health is particularly threatened under conditions of urban poverty. When basic infrastructure is inadequate, poor sanitation, drainage and impure drinking water aid in the transmission of infectious diseases, which puts poor urban households at high risk. Flooding causes infrastructure strain in any city but in poorer cities, sanitation is even more affected. Flooding often damages pit latrines (most common in Asian and African cities) and floodwaters are thus contaminated by the overflow from pit latrines and septic tanks with faecal material. This situation is worsened under circumstances of higher densities in urban areas. Climate change vulnerabilities thus require sound urban management and planning practices, and higher levels of investments in infrastructure, together with better-prepared local governments.

Hazard mapping makes it now possible to classify lands in urban areas by the degree of vulnerability to landslides, storm floods, sea level changes and other climate change impacts. Land identified as high-risk can then be zoned for zero construction or only for buildings of a highly regulated and appropriate standard. While these regulatory steps might be obvious, their implementation is more difficult when high risks zones are already occupied, and different uses, densities and status of occupation exist. Poverty forces many people to settle in areas of high risk and return to hazard-prone land that have already been struck by climate change induced events. Planning decisions regarding densely populated high-risk zones are inevitably contentious, not to mention costly if city governments need to expropriate with compensation.

Regulatory frameworks and compliance with the highest building standards for vulnerability reduction need to be introduced incrementally and target public buildings as a matter of priority. These include schools, hospitals and factories that pose risk to the environment if damaged during a natural disaster. Improvements to existing housing stock on the other hand, need to be dealt with on a case-by-case basis and strike a balance among compliance, affordability and relocation. This balance raises the critical issue and debate on how affordability affects climate action planning.

Indicators on per capita building energy consumption, on urban transport and urban density for example can help to inform planners and city managers on policy at several scales. For example, at the regional scale, growth and transportation strategies shape major infrastructural investments that impact decisions to drive or take transit. At the municipal scale, comprehensive development plans establish density targets that greatly impact the viability of transit service, district energy systems and efficient land use. At the neighbourhood scale, development guidelines promoting mixed-use communities enable opportunities to walk or cycle to meet daily needs, and at the parcel scale, appropriate building forms and orientation reduce heating and cooling loads (Cavens, Condon, Kellett and Miller 2008, 3).

Planning and management tools can help to address the critical link between emissions and urban form, particularly in terms of transportation and building energy consumption. For example, official plans, development guidelines, development permits, densification plans, transit planning and pricing building codes, and a number of other planning tools can help to address GHG emissions in cities as climate change mitigation strategies. However, the need for spatial data that links GHG emissions with urban form, with city expansion, and both existing and future proposed development is essential for effective planning. This is also necessary for locally relevant policy decisions and to build support and understanding by the public (Cavens et al. 2008, 1).

Adaptation strategies have been implemented by a number of cities in order to reduce vulnerabilities associated with climate change, mainly to protect citizens from heatwaves, floods and droughts. The following are examples of planning strategies that London and New York City have introduced in order to address climate change.

The City of London has detailed three climate impacts in the London Climate Change Adaptation Strategy: heat waves, floods and droughts, each considered as having both a high risk of consequence and vulnerability, as well as increasing probability.

The heat wave of 2003, during which 600 Londoners died, was a motivator in developing a strategy to adapt to and prepare for rising temperatures in the London area. Climate change scenarios have been developed by the Hadley Centre for Climate Prediction and Research (2005) that predict that London will see the increased frequency and intensity of extreme weather, as well as a rise in the number of "very hot" summer days. As a result of this data, the mayor of London has developed strategies to mitigate the effects of heat waves. The mayor is undertaking an "urban greening programme" that will utilize green spaces, street trees and urban design to cool the city. The mayor also intends to create an "Urban Heat Island Action Area" in which new development will be used to offset the heat island effect. Facilitating access to cool buildings and developing design guidelines for developers and architects are also elements of the key action plan to manage London's response to heat waves (Greater London Authority 2007).

London is prone to tidal flooding from the sea, fluvial flooding from the Thames River, surface water flooding due to the inability of the drainage system to handle heavy rainfall, flooding from sewers and flooding as a result of rising groundwater. Using maps of London that include areas at risk of tidal and fluvial floods and information from the Environmental Agency, the city of London determined that nearly 15 per cent of London is as risk from flooding. As a result of this data, the mayor proposes the review of the London Strategic Flood Response Plan, as well as improvement on the standard of flood risk management in partnership with the Environmental Agency. The urban greening programme will also help reduce flooding, as it will improve the permeability of the urban landscape. With rising temperatures causing the possibility of drought, and with each Londoner consuming an average of 168 litres of water per day, the city of London is looking to promote and facilitate the reduction of leakage from water mains, compulsory water metering, retrofitting of London homes as well as the encouragement of rainwater harvesting and grey water recycling. The Mayor proposes publishing a Water Strategy and a Water Action Framework that will achieve a sustainable water supply-demand balance (London Climate Change Adaptation 2008).

A second example of a planning and management in response to climate change that recognized the core requirement of indicators to inform its plan is embodied in the New York City – PlaNYC 2030 plan launched in 2007 and New York City Climate Risk Information report (2009). Mayor Bloomberg convened the New York City Panel on Climate Change (NPCC) in 2008 as part of PlaNYC, which established a set of indicators through which climate change could be measured and progress toward the goal to reduce carbon emissions by 30% by 2030 could be tracked. The framework includes indicators such as mean annual temperatures, infrastructure damage from climate-related factors, combine sewer overflow events and extreme wind events. The NPCC shows that according to global climate models (GCM), mean temperatures are likely to rise by 1.5 to 3 °F by the 2020s, 3 to 5°F by the 2050s, and 4 to 7.5°F by the 2080s. Similarly, extreme hot weather is very likely to increase and extreme cold weather very likely to decrease. 1-in-10 year and 1-in-100- year floods are expected to reoccur on average once every 1 to 3 years and 15 to 35 years, respectively, by the 2080s; with droughts which occur on average every 100 years expected to occur once every 8 to 100 years (NPCC 2009). As a result, the NPCC concluded that a rise in temperature, precipitation and sea level would most likely result in increased strain on materials, increased flooding, reduction of water quality and increased structural damage. New York City reports having planted more than 174,189 trees, converted 91 schoolyards into playgrounds and launched 224 city government energy efficient projects, among other developments (The City of New York 2009). By 2030, the plan aims to have reduced GHG emissions 30% below 2005 levels, organized a long-term effort to develop a comprehensive climate change adaptation strategy, and reduce its impact through focus on goals and indicators for five key dimensions of the city's environment- land, water, transportation, energy, and air (The City of New York 2007).

The planning process undertaken in New York City is instructive, both in terms of identifying the link between indicators and governance, but also in terms of the institutional mechanisms employed to implement the plan. For example, the city is dedicated to ensuring that vulnerable waterfront neighborhoods are involved in the development of community-specific climate change adaptation plans. A standardized process is being developed to engage community members, broaden their awareness of potential climate change impacts, and develop solutions that acknowledge each neighborhood's unique building type, relationship with the waterfront, and forthcoming community plans (The City of New York 2007).

A citywide cost-benefit strategic planning framework is also being created that will guide NYC's climate change adaptation policy. Components of this planning framework include a Climate Change Advisory Board made up of experts and government agencies, updated 100-year floodplain maps, aggressive floodplain management standards to ensure discounted flood insurance, and building code amendments that address the potential for flooding, droughts, high winds, heat waves, and utility service failures (The City of New York 2007).

In 2006, NYC's emergency response plan was created in preparation for future extreme weather events (The City of New York 2007). It takes into account the predicted impacts of violent storms on the city's airports and tunnels, outlines the city's flood evacuation zones and coordinates the efforts required to evacuate up to three million people. Supplemental to the emergency response plan is a disaster recovery initiative and a 2009 New York City Hazard Mitigation Plan that recognizes the potential need for rapidly providing large quantities of relief housing after such an event (The City of New York 2007).

3.3 Addressing Risk and Vulnerability in Cities through a more Empowered, Cohesive and Inclusive Governance

Over the past few decades, efforts to improve and strengthen urban governance have focused on the essential first step of decentralization of power, authority and resources from the central to municipal and neighborhood level. Governed by the principle of subsidiarity, decentralization processes seek to ensure that decisions are taken, and services delivered, at the sphere of government closest to the people while remaining consistent with the nature of the decisions and services involved. The importance of national recognition and engagement with cities as well as a cooperative and supportive role by provinces/states in urban development has been underlined in many decentralization strategies. A responsible fiscal federalism that positions cities as critical partners in the governing relationship is now being recognized as a pivotal policy platform for global action on climate change and local responsibility for mitigating climate change and building climate resilient cities.

World trends in urbanization are causing urban populations to spread out beyond their old city limits, rendering the traditional municipal boundaries, and by extension, the traditional governing structures and institutions, outdated. Single city jurisdictions of the past are being made more complex by multiple city jurisdictions that spread outward and build large and complex metropolitan governance systems. For example, the metropolitan area of Mexico City (18 million people) extends over the territories of municipalities of two states as well as the Federal District to include as many as 58 municipalities and the metropolitan area of Buenos Aires covers the territories of the City of Buenos Aires (3 million people) and the 32 municipalities of the Province of Buenos Aires (9 million people). Similarly, in Africa, Metropolitan Johannesburg (7.2 million people) encompasses Ekurhuleni (made up of the East Rand), the West Rand District Municipality (the West Rand) and the City of Johannesburg (Cameron 2005). Abidjan (with a population of 3.5 million) has expanded to encompass 196 local government units that include municipalities and surrounding rural areas (Stren 2007). In Asia, the Metropolitan Manila Area in the Philippines is composed of 10 Cities and 7 municipalities, with a total population of approximately 11 million; while Cebu City is comprised of seven cities and six municipalities (with a population of 1,930,096). The Tokyo metropolitan region, with an estimated population of 35 million, contains 365 municipal areas (Sorensen 2001, 22). In North America, Metropolitan Minneapolis-Saint Paul (with a population of 3,502,891 people) is composed of 188 cities and townships (Hamilton 1999). Portland, Oregon, with approximately 1.5 million inhabitants, covers 3 counties and 24 local governments.

As urban areas around the world continue to expand both in terms of density and horizontal space (Angel, Sheppard and Civco 2005), there is a need to govern these large areas in a coherent fashion. Highly fragmented governance arrangements in many metropolitan areas make efficient planning, management and urban financing for area wide service provision a difficult and on-going challenge (Klink 2007; Lefèvre 2007). Climate change action however requires coherence and integration across these jurisdictions.

This metropolitan expansion is not just in terms of population settlement and spatial sprawl but perhaps more importantly, in terms of their social and economic spheres of influence. The functional area of cities has extended beyond the jurisdictional boundaries. Cities have extensive labor markets, real estate markets, financial and business markets and service markets that spread over the jurisdictional territories of several municipalities and, in some cases, over more than one state or provincial boundary. In a number of cases, cities have spread across international boundaries. This expansion is taking place regardless of municipal jurisdictional boundaries. Increasingly, effective climate change action demands more integrated planning, service delivery and policy decisions than these multiple but individually bounded cities can provide. A decision taken in one municipality that is part of the larger city affects the whole city. This phenomenon introduces new challenges of governance and in particular, metropolitan governance on climate change. There is a need to govern these large areas in a coherent fashion since they are the staging sites for meeting the serious challenges of climate change in the future.

Building effective and long-term solutions to climate change requires a city governance approach which acknowledges the respective roles and contributions of a wide array of actors. An inclusive city government that involves long-term residents, international migrants, the poor, marginalized groups, national minorities and indigenous peoples is fundamental to building safe, liveable and climate resilient cities. The development of new policies and mechanisms for local governance is rooted in strong grassroots participation, that citizens and community groups are equipped with the understanding of democratic governance to hold local and more senior levels of government accountable, and that the poorest and most isolated communities are represented in the public debate. Addressing climate change risk in cities thus depends on the availability and accessibility of information on climate risks and an engaged, informed urban citizenry involved in the formulation of climate action plans.

Tanner, et al. (2008) identify specific characteristics of good urban governance that improve urban climate resilience. The authors stress that improving citizens' access to information and maintaining a relationship of accountability between local governments and their citizens are key to improving cities' climate resilience (2008, 21).

City indicators that measure the effects of climate change on cities and assess urban climate risk are crucial to the development of a proactive system for anticipating changing climate conditions and preparing for extreme climate events. The 2004 Tsunami in Chennai motivated the identification of hazard prone areas in the city's Draft Master Plan (Tanner 2008, 23). Projections of sea-level rise and increased intensity of precipitation have been used to inform Cochin's infrastructure planning and foster community-centred disaster management policy (Tanner 2008, 24). Participation and Inclusion is closely related to the need for transparency, accountability, and information disclosure for good urban governance. Publishing information on official websites and providing procedures for citizens to request information ensures access to information for urban residents. Media and internet access, education levels, income levels, and local government's information disclosure culture determine the success of participatory and inclusive processes (Tanner 2008, 26).

Engaging citizens in the running of their city can take many forms and experiences in cities worldwide are being well documented. Typical steps include public consultations, public hearings and meetings, appointing citizens to advisory bodies inside municipal authorities, and designing community councils with stakeholder voice at municipal council sessions. Valuable research and evaluations have been undertaken of recent experiments involving citizen engagement in environmental and neighbourhood impact studies, in the establishment of people's councils, in the inclusion of non-governmental organizations and other representatives from the private sector on local service boards and development councils in preparing development programs, allocating funds, and participating in planning and design initiatives for communities, in popular initiatives to put forward urban laws, and in the practice of participatory budgeting (McCarney 1996).

The case of Chicago's Climate Action Plan is instructive. On September 19, 2008, the City of Chicago released its Climate Action Plan to the public after a complex development process that incorporated involvement and input from institutions, businesses and communities throughout the city. The plan is an example of the merits of evidence-based planning as its goals and actions are grounded in scientific regional climate impact projections and greenhouse gas emissions accounting (Parzen 2008, 3).

Although initially Chicago's incomplete knowledge base on climate and emissions analysis raised challenges for the Action Plan's development progress, solid research into the City's sources of emissions helped to formulate financially viable emissions reduction targets, legitimized the overall planning process, and enhanced participants' understanding of Chicago's contribution to and risk from global climate change impacts. Projecting Chicago's future climate impacts and adaptation challenges helped to convey the reality of the situation to the community and participating partners. An emissions inventory for the city's buildings illustrated the importance of engaging every Chicago household in the process of emissions reductions. Analysis of a range of potential actions and their combined ability to achieve Chicago's 2020 emissions reduction goal of 25% off 1990 levels allowed leaders to justify the city's actions to their constituents and track progress (Parzen 2008, 8).

Generating and maintaining public support was crucial as the Climate Action Plan's development depended upon funding sources from within the community. As previously noted (on page 19), the Chicago Climate Action Plan reveals the importance of securing a range of sustainable funding sources to support the development process from research and planning to implementation. In total, US$2,789,000 was contributed by 14 sources from a variety of non-profit foundations, funds, trusts and initiatives as well as pro bono services, Illinois and Chicago government departments, and regional councils (Parzen 2008, 10). As a model, it must be noted that a city developing its climate action plan requires funding to manage public communications and engagement, to analyze its baseline emissions, and to evaluate the GHG emission reduction potential of various mitigation strategies available within the specific context of that city (Parzen 2008, 9).

The process of developing Chicago's Climate Action plan led participants to realize the need for a standard global methodology for measuring different actions' potential to reduce GHG emissions (Parzen 2008, 8). Specific impact analyses may not be required for every city, thus existing research and a globally standardized methodology will be useful for the development of other cities' guides and plans for climate change adaptation and mitigation.

4. CONCLUSION

This paper has mapped the core risks for cities associated with climate change through literature review and city case studies and has examined the use of city indicators in assessing and addressing these risks and vulnerabilities in cities. The paper has explored how knowledge derived from city indicators on climate change could help to direct a more informed set of planning norms and practices, more effective infrastructure investment and urban management, and a more inclusive urban governance.

An argument has been put forward that indicators on cities and climate change can add new policy leverage for local governments, in terms of building empowered decision-making in this volatile policy field, in developing evidence-based policy-making, and in building strong city governments capable of performing as new sites of governance in global negotiations on climate change and in decision-making related to risk assessments.

In building this argument and identifying the potentials and opportunities for cities to increasingly play an active, and indeed critical, role on the global climate agenda, a core set of challenges are recognized. First, research challenges in this emerging field of cities and climate change can be identified. Based on the mapping of risks in section one of this paper, gaps in city indicators and/or weaknesses in methodologies for comparative indicators on cities and climate change pose important challenges for researchers, international agencies and cities and their communities globally. Second, governance challenges for cities that arise as a result of new risks and vulnerabilities associated with climate change can be identified.

Based on the mapping of governance, planning and management responsibilities in section.... new challenges emerge for city governments in addressing climate change and developing climate action plans. This dual set of challenges will be presented here by way of conclusion but more importantly to serve as a roadmap for next steps if cities are to be successful in confronting climate change risks and building more climate resilient cities in the future.

4.1 Research Challenges for Improved Measurements, Indicators and City Data on Climate Change

The vulnerability of cities to climate change is largely underestimated due to a lack of climate data that is localized and specific to the city level. There is no established set of city indicators that measures the effects of climate change on cities and assesses those risks, or is there a comprehensive set of indicators with a common accepted methodology designed to measure the impact that cities have on climate change and the role that cities play in contributing to green house gas emissions. There are a number of research challenges in the field of cities and climate change that emerge from this paper.

One cluster of challenges relates to how best to localize measurements on climate change. First, cities are responsible for the majority of the world's greenhouse gas emissions yet there is still only a very limited set of comparable measurements of climate change at the city level. While national and global measurements have advanced, a credible and globally standardized measurement for how cities impact climate change is needed. Second, and related to this, is the challenge for cities to also establish mitigation targets that will help to lessen cities impact on climate change. Establishing such targets requires sound research by sector that can help cities to establish benchmarks against which to measure performance in moving towards these targets. Ideally, these benchmarks are established with a globally comparative methodology so that global progress can also be measured in a standard format. A third set of measurement challenges relates to cities and climate change adaptation. Research on risk and vulnerability of cities to climate change needs to inform citizens and policy makers across specified categories of risk at the city level. Data by category of risk and varying degree of vulnerability can then lead to an informed policy agenda on climate adaptation and emergency preparedness.

A second set of challenges for research on cities and climate change is associated with establishing a globally comparative, standardized set of measures through common methodologies. Climate change is often monitored at global and national levels according to an adopted set of measures globally agreed upon by states. However, similar statistics are rarely collected at the city level and devising indicators on climate change at the city level is proving difficult. Furthermore, when individual cities collect and monitor data on climate change, the information is often collected using methodologies different from other cities that is analyzed and reported on in different ways. This creates further challenges for researchers when drawing comparisons across cities globally. The lack of a standardized methodology for devising indicators on climate change at the city level greatly affects the quality of research, especially at the city level. Quality research on the effects of climate change in cities is often difficult to achieve since comparisons, benchmarks, and indicators across cities are lacking.

A third set of research challenges on cities and climate change is associated with the complexities of city level politics, multiple and overlapping agency responsibilities for service sectors, and spatial challenges for measurement associated with municipal jurisdictional boundaries. Conceptualizing vast, and often diffuse, urban territories and their spread across existing municipal boundaries and broader jurisdictions are difficult tasks. This conceptual challenge mirrors a movement in local governance reform that is in a continuous state of flux, experiment and re-formulation.

Metropolitan areas around the world, with a few exceptions, are made up of more than one urban unit. However most of our comparative statistics on cities and metropolitan areas are based on data with some limitations in terms of reliability and comparability due to definition issues on jurisdictional boundaries. For example, urban areas or metropolitan areas made up of more than one urban area are defined by each country and no consistent definition for what is "urban" or what is a "municipality" throughout the world exist. And because metropolitan areas are rarely legally defined entities, there may be a number of different possible boundaries for a commonly understood extended urban area. For example, there is New York City and the New York Metropolitan Area, and there is the City of Toronto and the Greater Toronto Area. In all these cases, different designations will mean different area measurements, service areas and populations. Not only do inconsistent definitions pose challenges for research, but also for performance targets, indicators and measurements in the field of climate change.

The World Bank's Global City Indicators Program provides indicators that can assist cities with their mitigation and adaptation efforts in climate change but there are still many gaps in data needed on climate change. The Program has various indicators that can assist cities with climate change mitigation strategies including indicators on modal shifts from road transport to rail and public transport and non motorized transport; waste incineration; wastewater treatment and recycling;

etc. Indicators on cities and greenhouse gas emissions are under development that can help to create a standard and globally recognized index on cities and GHG emissions. More research on indicators is required that further addresses mitigation strategies in the energy supply sector including indicators on renewable energy resources and the monitoring of industry practices in cities. With regard to mitigation strategies in the buildings sector, LEED, BREEAM, CASBEE, and GreenStar green building rating systems (to name a few) have provided leadership in promoting environmentally friendly buildings and has transformed the building industry. Existing building retrofit strategies through these rating systems in numerous cities worldwide are now deepening this experience.

Indicators on adaptation strategies can help cities assess progress in addressing climate change and identify areas requiring improvement. With regard to infrastructure for example, standards and regulations that integrate climate change considerations into design are as yet underdeveloped and measure on performance are not yet identified. In addition, specific land-use policies for climate adaptation have not been well addressed. In the health sector, research is required on climate change health impacts necessary for informing local health policy, for example in creating heat-health action plans. Indicators are also needed to monitor climate sensitive diseases. More generally, the ability of health services to cope with climate change associated health risks is under-researched. The issue of energy demand (particularly in warmer cities) is shown here to be potentially very significant, especially in economic terms, and this should also be a priority. Climate change impact assessments on water scarcity in cities and how cities can best create adaptation responses warrants further research and the design of impact measures is then needed. Generally, in this evolving field of climate change adaption at the city level, much more work is needed on impact assessment and on the evaluation of adaptation responses including the economics of adaptation.

4.2 Governance Challenges for Building Climate Resilient Cities in the Future

The governance of cities is pivotal in confronting the challenges of climate change. City governments are constrained however on a number of fronts when it comes to formulating and implementing climate action. Many city governments are weakened due to only limited power and responsibility over key public services, including planning, housing, roads and transit, water, land-use, drainage, waste management and building standards. In many of the poorest cities of Asia, Africa and Latin America, under-serviced informal areas of the city do not have basic services such as waste collection, piped water, storm and surface drains and sanitation systems, placing large portions of cities at even higher risk of climate change impacts, particularly from storms, flooding and heat waves. City governments often lack powers (with respect to higher orders of government — state and national) to raise the revenues required to finance infrastructure investments and address climate change challenges. When governance capacity is weak and constrained, cities are limited in their abilities to take action on climate change.

Deficient intergovernmental relations, inadequate popular local representation processes, weak sub-national institutions and poor financing mechanisms to support these sub-national government forms, pose critical questions for policy makers and leaders in all level of government, as well as for researchers, planners and international agencies concerned with climate change.

Addressing climate change risk in cities must also be considered in a broader framework of risks associated with poverty. Cities in the 21st century are facing unprecedented challenges. The world's urban population is likely to reach 4.2 billion by 2020, and the urban slum population is expected to increase to 1.4 billion by 2020, meaning one out of every three people living in cities will live in impoverished, over-crowded and insecure living conditions. The situation of poverty in cities worldwide, but in particular in the less developed regions, must be recognized as a core factor in addressing climate change and building more climate resilient cities. This means explicitly recognizing that climate change adaptation must reduce the vulnerability of the poor in cities.

A significant challenge confronting the larger metropolitan centers in addressing climate change is that associated with fragmentation. As urban populations grow and spread out beyond the old city limits, the traditional municipal boundaries, and by extension, the traditional governing structures and institutions are increasingly outdated. Highly fragmented governance arrangements in many metropolitan areas make efficient planning, management and urban financing for climate action planning a difficult challenge. Climate change action requires coherence and integration across these jurisdictions.

When considering climate action in these large metropolitan areas, whether in terms of measuring risks, establishing indicators, creating mitigation or adaptation strategies, the challenges of metropolitan governance and the contexts of administrative, management and political fragmentation are critical to confront.

Urban metropolitan areas demand and consume vast amounts of energy and water and other material resources that impact climate change. Cities are both victims and perpetrators of climate change. They generate the lion's share of solid waste, electricity demand, transport related emissions, and space-heating and cooling demand. On the other hand, cities and local governments are well positioned to set the enabling framework for climate change mitigation strategies and for taking a leadership role in addressing the challenges related to hazard mitigation and vulnerability assessment as countries adapt to climate change. For cities to effectively address climate change, coordination and overcoming the problems of fragmentation in political institutions locally is a core requirement.

Five core governance challenges can be identified that are at the base of successful climate action:

1. Effective leadership is critical for overcoming fragmentation and building consensus in cities if effective climate action planning is to be achieved. Strong leadership can overcome individualism and competition across political 'turf' and build recognition that more metropolitan wide collective action on climate change is empowering at both a national and international levels. The ability to build consensus and coordination better facilitates investments in infrastructure and amenities that make the metropolis more resilient to climate change. Strong leadership in the affairs of metropolitan governance means not only building consensus, but also aggregating these fragmented interests in a way that builds legitimacy and accountability to stakeholders in the process.

2. Efficient financing is a core requirement for climate action by cities. Success to date with efforts to confront climate change challenges in cities has been hampered due to deficient financing tools at local levels of government. The redistribution of responsibilities between different levels of government has not always been sustained by a corresponding allocation of resources or empowerment to adopt adequate financing tools needed to raise these resources. If these weaknesses are common at the level of individual municipalities, then the problems of raising finance to support the broader metropolitan areas are compounded. Highly fragmented governance arrangements in many metropolitan areas make efficient financing for area wide climate mitigation and adaptation strategies a difficult and on-going challenge. As witnessed in the Chicago Climate Action Plan, raising funds to support the effort required substantial effort and collaborative work. Without a clear, permanent and sufficient financial mechanism it is indeed quite difficult to implement planning for more climate resilient cities.

3. Effective citizen participation and access to information. Improving citizens' access to information and maintaining a relationship of accountability between local governments and their citizens are critical to improving a city's climate resilience. Principles of transparency and democracy require that the mechanisms of participation are accessible, easy to be understood and with simple forms of representation. Addressing climate change risk in cities depends on the availability and accessibility of information on climate risks and an engaged, informed urban citizenry involved in the formulation of climate action plans.

4. Jurisdictional Coordination is one of the most pressing governance challenges common to cities worldwide. This challenge takes two forms: multi-level jurisdictional coordination of services vertically across multiple levels of government and inter-jurisdictional coordination of services horizontally across the metropolitan area. In the case of the former, the inter-governmental relations involved in the governance of cities are often in flux with extensive and complex decentralization processes in motion in many countries worldwide. Multiple tiers of government and various levels of state agencies are involved in the climate change agenda and vertical coordination is often weak or non-existent. In the case of the latter, existing governing institutions are often horizontally fragmented, uncoordinated and in many cases ad-hoc when it comes to climate change strategy, due to multiple jurisdictional and electoral boundaries that span the territories of vast metropolitan areas. Coordination is fundamental not only in basic areas such as land, transport, energy, emergency preparedness and related fiscal and funding solutions, but in addressing issues of poverty and social exclusion through innovative mechanisms of inter-territorial solidarity.

5. Land-use Planning is a key criterion for effective city governance in the arena of climate change strategies. Territorial and spatial strategies are key to addressing climate change risks and building effective mitigation and adaptation strategies. Land use and transport planning in cities at urban and regional levels are core requirements in addressing climate change in cities worldwide. Managing transportation, land us, and other related infrastructure investments in large metropolitan areas (and their peri-urban areas) is essential for the advancement of the climate change agenda and addressing GHG emission targets. These investments and services however are often implemented, financed, managed and regulated by different governing institutions and levels of government. Coordination of these processes relies on complex intergovernmental policy networks and organizational management. This coordination is an essential basis for making progress on the climate change agenda in cities globally.

References

Agencia de Protección Ambiental, Gobierno de la Ciudad de Buenos Aires. 2008. *Plan Estratrégico 2008-2012*. Buenos Aires.

Angel, S., S.C. Sheppard and D.L. Civco. 2005. *The Dynamics of Global Urban Expansion*. Transport and Urban Development Department, Washington, DC: The World Bank.

Cameron, R. 2005. "Metropolitan Restructuring (and more Restructuring) in South Africa", *Public Administration and Development* 25 (4).

Cavens, Duncan, Patrick Condon, Ronald Kellett, and Nicole Miller. 2008. *Policy, Urban Form and Tools for Measuring Greenhouse Gas Emissions*.

City of London Corporation. 2007. *Rising to the Challenge - The City of London Climate Change Adaptation Strategy*. First Published May 2007, Revised and Updated January 2010.

Clinton Foundation. www.clintonfoundation.org.

Dhakal, Shobhakar. 2004. *Urban Energy Use and Greenhouse Gas Emissions in Asian Mega-Cities*. IGES.

ERM. 2007. *Global City Indicators: Definitions and Methodologies*. Report Submitted to The World Bank April 5.

Glaeser, Edward L. and Matthew Kahn. 2008. *The Greenness of Cities*. Cambridge: Rappaport Institute and Taubman Center.

Greater London Authority. February 2007. London CO_2: *Action Today to Protect Tomorrow: The Mayor's Climate Action Plan*. London.

Hadley Centre Publication. January 2005. *Stabilising Climate to Avoid Dangerous Climate Change – A Summary of Relevant Research at the Hadley Centre*.

Hamilton, D. 1999. *Governing Metropolitan Areas*. New York: Garland Publishing.

Henstra, Dan, and Gordon McBean. 2003. "Climate Change, Natural Hazards and Cities." Paper prepared for Natural Resources Canada, Institute for Catastrophic Loss Reduction.

Hezri, A.A., and S.R. Dovers. 2006. "Sustainability Indicators, Policy and Governance: Issues for Ecological Economics". *Ecological Economics* 1 (60): 86–99.

Hillman, T. and A. Ramaswami. 2010. "Greenhouse Gas Emission Footprints and Energy Use Benchmarks for Eight US Cities." *Environmental Science & Technology* (Accepted December 3, 2009).

Hunt A. and P. Watkiss. 2007. *Literature Review on Climate Change Impacts on Urban City Centers: Initial Findings*. OECD.

ICLEI CCP Network. "5 Top Energy Efficiency Measures Implemented in ICLEI's CCP Network in South Africa."

ICF International, Toronto Atmospheric Fund and Toronto Environment Office. 2007. *Greenhouse Gases and Air Pollutants in the City of Toronto: Toward a Harmonized Strategy for Reducing Emissions*. Toronto: City of Toronto.

Innes, J.E. 1998. "Information in Communicative Planning." *Journal of the American Planning Association* 64 (1): 52–63

IPCC (Intergovernmental Panel on Climate Change). 2007. "Climate Change 2007: Synthesis Report – Summary for Policymakers." Assessment of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, IPCC: Cambridge University Press.

Kennedy, C.A, Ramaswami A., Carney S. and Dhakal S. 2009. "Greenhouse Gas Emission Baselines for Global Cities and Metropolitan Regions." (Draft Paper).

Kessler, E., N. Prasad, F. Ranghieri, F. Shah, R. Sinha, and Z. Trohanis. 2009. *Climate Resilient Cites: A Primer on Reducing Vulnerabilities to Disasters*. Washington, DC: The World Bank.

Klink, J. 2007. Forthcoming. "Recent Perspectives on Metropolitan Organization, Functions and Governance". In *Governing the Metropolis*, ed. Rojas E., J. Cuaudrado-Roura and F.J. Guell. Washington, DC: IADB.

Kreimer, A., M. Arnold, and A. Carlin, ed. 2003. *Building Safer Cities: The Future of Disaster Risk*. Washington, DC: World Bank.

Lefèvre, C. 2007. "Democratic Governability of Metropolitan Areas: International Experiences and Lessons for Latin American Cities." In In *Governing the Metropolis*, ed. Rojas E., J. Cuaudrado-Roura and F.J. Guell. Washington, DC: IADB.

McCarney, Patricia L., ed. 1996. *Cities and Governance: New Directions in Latin America, Asia and Africa.* Toronto: University of Toronto Press.

Mega V., and J. Pedersen. 1998. *Urban Sustainability Indicators.* The European Foundation for the Improvement of Living and Working Condition.

Metro Vancouver. January 2009. *Metro Vancouver Sustainability Report*. Vancouver.

New York City Panel on Climate Change. February 2009. *Climate Risk Information*. New York City.

Parzen, J. 2008. *Lessons Learned: Creating the Chicago Climate Action Plan*. Chicago Climate Action Plan.

San Francisco Department of the Environment, San Francisco Public Utilities Commission. September 2004. *Climate Action Plan for San Francisco: Local Actions to Reduce Greenhouse Gas Emissions.* San Francisco.

Science Daily. 2003. "Are Cities Changing Local and Global Climates?" http://www.sciencedaily.com/releases/2003/12/031212080526.htm.

______. 2009. "Sea Level Could Rise from 0.75 to 1.9 Meters This Century." http://www.sciencedaily.com/releases/2009/12/091207165252.htm.

Secretaria del Medio Ambiente del Distrito Federal. 2008. *Mexico City Climate Action Program 2008-2012.* Mexico City.

Sorensen, A. 2001. "Subcentres and Satellite Cities: Tokyo's 20th Century Experience of Planned Polycentrism." *International Planning Studies* 6 (1) : 9–32.

Stren, R. 2007. Forthcoming "Urban Governance in Developing Countries: Experiences and Challenges." In *Governing Cities in a Global Era: Urban Innovation, Competition, and Democratic Reform*, ed. Robin Hambleton and Jill Gross. New York, NY: Palgrave Macmillan.

Tanner, T.M., T. Mitchell, E. Polack, and B. Guenther. 2008. "Urban Governance for Adaptation: Assessing Climate Change Resilience in Ten Asian Cities." Report to Rockefeller Foundation, Institute of Development Studies, University of Sussex, UK.

The City of Miami. June 2008. *MiPlan: City of Miami Climate Action Plan*. Miami.

The City of New York. 2007. PlaNYC: *A Greener, Greater New York*. New York City.

_______. 2009. PlaNYC: *Progress Report 2009*. New York City.

The City of Portland, Multnomah County. June 2005. *A Progress Report on the City of Portland and Multnomah County Local Action Plan on Global Warming*. Portland.

The City of Stockholm. March 2007. *Adapting to Climate Change in Stockholm*. Stockholm.

United Nations. 2007. *Global Report on Human Settlements: Enhancing Urban Safety and Security*. Nairobi: UN-HABITAT.

United Nations. 2008a. *State of the World's Cities 2008/2009*. Nairobi: UN-HABITAT.

United Nations. 2008b. *The Millennium Development Goals Report*. New York: United Nations.

USEPA (United States Environmental Protection Agency). 2007. *National Environmental Performance Track*. www. Epa.gov

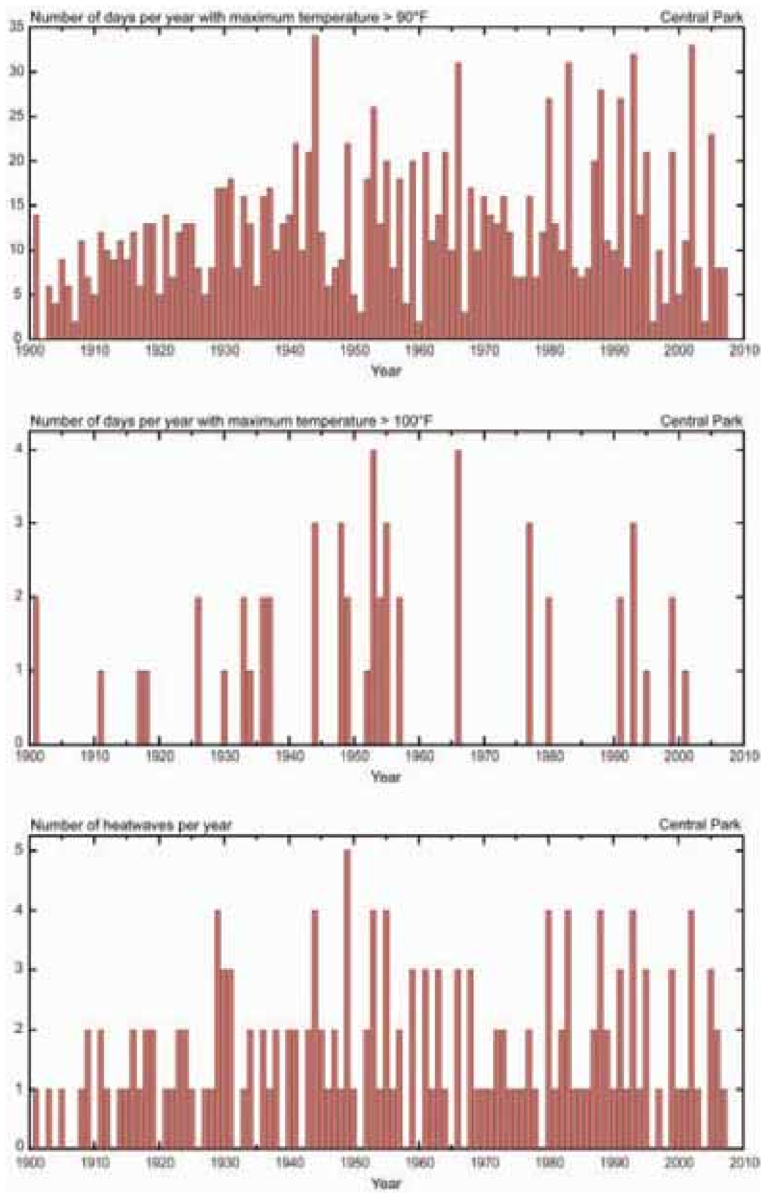
Vermeer, M., and Stefan Rahmstorf. 2009. **Global Sea Level Linked to Global Temperature**. *Proceedings of the National Academy of Sciences.* http://www.pnas.org/content/106/51/21527

Yale University. 2008. *Environmental Performance Index, Summary for Policymakers.* Yale Center for Environmental Law and Policy.

APPENDIX A

Observed High Temperature Extremes in Central Park, Manhattan

(Based on maximum temperatures exceeding 90°F and 100°F, and as heat waves, exceeding 90°F for three consecutive days)



Source: New York City Panel on Climate Change 2009. *Climate Risk Information.*

APPENDIX B

TABLE 1
Measurements of Sea Level Rise in New York City, Miami, Stockholm and Vancouver

Sea level rise	New York City	Miami	Stockholm	Vancouver
Method-ology	Sea level data is collected at the Battery. Data available from NOAA. Water-level records combine data on ocean fluctuations and vertical motion of the land at the station. The sea-level variations determined by these records include the linear trend, the average seasonal cycle, and the interannual variability at each station. Monthly data through the end of 2006 were used in the calculation, and all stations had data spanning a period of 30 years or more.	Sea level rise measured in Key West, Florida. Data source: the Proudman Oceano-graphic Laboratory's Permanent Service for Mean Sea Level (PSMSL). The monthly sea level data are calculated using daily data. The mean monthly sea level data based on four measurements per day are very close to the observations with 1-hour interval. It is estimated that the error does not exceed 2 cm with probability of 99.7%. The annual sea level based on 4-hour interval observations coincide with results based on 1-hour observing intervals.	Sea level measured in Stockholm. Data measured by the Swedish Meteoro-logical and Hydrological Institute. Sealevel is measured in relation to a certain benchmark. Values are given in cm above mean sealevel (MW). Long timeseries of yearly means are needed to calculate a regression line in order to take care of the land uplift. The value on the regression line for a certain year determines the mean sea level for that year.	Water levels along the British Columbia coast are recorded by tide gauges at stations maintained by the Canadian Hydrographic Service and the Water Survey of Canada. This indicator reports data from four tide gauge stations with long records that broadly represent three coastal oceanic regions. Sea level data were obtained from the Marine Environ-mental Data Service (MEDS) of Fisheries and Oceans Canada. Trends were fitted to annual mean values to assess mean sea level rise. Trends were determined using the Microsoft Excel template MAKESENS, and statistical analyses to remove any autocor-relation (using the prewhitening procedure described in Wang and Swail 2001).
Data	Rates of sea level rise in New York City range between 0.86 and 1.5 inches per decade, with a long-term rate since 1900 averaging 1.2 inches per decade.		During the period 1961–2003, sea levels rose by 8 cm as a direct consequence of the expansion of sea-water and glaciers melting. The rise in sea levels has doubled in speed compared to the period of 1961-2003.	For Metro Vancouver the trend is a 2 centimetre increase in the mean sea level every 50 years.

CHAPTER 2

Detecting Carbon Signatures of Development Patterns across a Gradient of Urbanization: Linking Observations, Models, and Scenarios

Marina Alberti* and Lucy R. Hutyra

SUMMARY

Urbanizing regions are major determinants of global and continental scale changes in carbon budgets through land transformation and modification of biogeochemical processes (Pataki et al. 2006). However, direct measurements of the effects of urbanization on carbon fluxes are extremely limited. In this paper we discuss a strategy to quantify urban carbon signatures (spatial and temporal changes in fluxes) through measurements that can more effectively aid urban carbon emissions reduction scenario and predictive modeling. We start by articulating an integrated framework that identifies the mechanisms and interactions that link urban patterns to carbon fluxes along gradients of urbanization. Building on a synthesis of the current observational studies in major US metropolitan areas, we develop formal hypotheses on how alternative development patterns (i.e., centralized versus sprawling) produce different carbon signatures and how these signatures may in turn influence patterns of urbanization. Finally, we discuss the fusion of observations, scenarios, and models for strategic carbon assessments.

*Corresponding author: malberti@u.washington.edu

1. INTRODUCTION

Urbanizing regions are major determinants of global and continental scale changes in carbon budgets (carbon sources and sinks) through land transformation and modification of biogeochemical processes (Pataki et al. 2007). Recent studies in urbanizing regions provide increasing evidence of the complex mechanisms by which urban activities affect both carbon emissions (Gurney et al. 2009) and stocks (Hutyra et al. 2011; Churkina et al. 2010). However, scarce empirical data on the effects of urbanization on carbon fluxes limit our ability to establish the underlying processes and mechanisms linking urbanization patterns and carbon fluxes. Further, the exact magnitude of and mechanisms for carbon exchange are largely uncertain for urbanizing ecosystems (Pataki et al. 2006). Also unknown is how patterns of urbanization interact with household behaviors and consumption choices. Typically, quantifications of carbon emissions are based on estimates of fossil fuel consumption from human activities (Grimmond et al. 2002). Similarly, changes in carbon uptake of vegetation are often generated from remote sensing-based estimates of biomass stocks (Imhoff et al. 2004) and ecosystem models are largely parameterized for 'natural' conditions (Churkina 2008). These estimates are inadequate to understand the relative magnitude of multiple urban activities, household behaviors, and their variability across alternative development patterns (i.e. urban form, land use intensity, infrastructure). Predictions of future trajectories of carbon fluxes associated with urbanization require an understanding and systematic evaluation of how alternative patterns of urban development (i.e., centralized versus sprawling) affect the carbon budget over the long term.

United Nations estimates suggest that half the world's population was living in urban areas by the end of 2008 and about 70 percent of the global population is projected to become urbanites by 2050 (UNFPA 2007). The process of urban expansion results in complex patterns of intermixed high- and low-density built-up areas and a fragmentation of the natural landscape. Urbanization affects ecological processes both directly — by simplifying habit in human-dominated systems - and indirectly — by changing the biophysical attributes of the landscape that result in a variety of interrelated local and global effects (Alberti and Marzluff 2004). The complex interactions among urbanization, carbon fluxes, and ecosystem functions are influenced by both human and biophysical factors and competing positive and negative feedbacks between them. The integrated effects of urbanization (including changing land cover characteristics, land use patterns, pervious surface fractions, urban heat islands, atmospheric pollution, management activities, etc.) on land-atmosphere exchange processes for both energy and carbon remain highly uncertain despite decades of study on elements of the problem. We hypothesize that in temperate, urban ecosystems key mechanisms that affect vegetative carbon stocks vary discontinuously across a gradient of urbanization.

Imhoff et al. (2004) estimated that urbanization has reduced net primary production (NPP) by 0.04 Peta grams of carbon per year (a 1.6% overall reduction) for the USA, but the overall uncertainty remains very high due to incomplete data and understanding of the feedbacks. Change in NPP due to urbanization also differs regionally based on the ecosystem and biome. At local and regional scales, urbanization can increase NPP in resource-limited regions. Imhoff et al. (2004) show that through localized warming, "urban heat islands" can extend the growing season in cooler regions (such as Seattle, WA) and increase NPP in winter. However, benefits like these may not offset the overall negative impact of urbanization on NPP for cities in highly productive biomes (Imhoff et al. 2004). Urbanization also may increase NPP in resource-limited, low-productivity regions by increasing water availability in arid areas (such as Phoenix, AZ). For example, Buyantuyev and Wu (2008) showed that urbanization increased regional NPP in central Arizona in dry years. Introduced plant communities (e.g., urban vegetation and crops) have higher NPP than the natural desert, and taken together urban and agricultural areas contributed more to the regional NPP than the desert vegetation in normal, but not in wet years. Because urbanization disrupts the coupling between vegetation and precipitation and increases spatial heterogeneity, NPP of this arid urban landscape is only weakly correlated with rainfall pattern but is strongly correlated with population characteristics (i.e. median family income) (Buyantuyev and Wu 2008).

In this paper, we develop a strategy to quantify urban carbon signatures (spatial and temporal changes in fluxes) through measurements that can more effectively aid urban carbon scenario and predictive modeling. We start by articulating an integrated framework that identifies the mechanisms and interactions that link urban patterns to carbon fluxes along gradients of urbanization. Building on a synthesis of the current observational studies in major US metropolitan areas, we develop formal hypotheses on how alternative development patterns produce different carbon signatures and how these signatures may in turn influence patterns of urbanization. We then identify a set of observations and research designs to test such hypotheses using the Seattle, WA region as a case study. Finally, we discuss the fusion of observations, scenarios, and models for strategic carbon assessments.

2. URBAN CARBON CYCLE

The net carbon balance of an urban region is the results of anthropogenic carbon emissions and ecosystem exchange processes. Attribution and accounting of emissions can be difficult in the urban context since emissions can be generated in one location, but be due to demand at another location (e.g. electricity generation vs. consumption). The discussion which follows is centered on vegetative carbon fluxes, but anthropogenic emissions and biogenic sources/sinks are both central to understanding urban carbon dynamics.

In considering the vegetative urban CO_2 (C) cycle, it is important to carefully differentiate the coupled changes in carbon stocks versus changes in carbon fluxes. A carbon stock is a pool of carbon that can be in a solid, liquid, or gaseous state (e.g. plant woody material). A carbon flux is an addition or subtraction from a carbon pool (e.g. plant photosynthesis or combustion). Characterizing carbon stocks in the form of soil carbon, dead woody debris, and live vegetation is central in determining the net ecosystem productivity (NEP) of an area and overall habitat characteristics. NEP is the difference between gross primary productivity (GPP, plant photosynthesis) and ecosystem respiration both in terms of autotrophic plant maintenance respiration (R_A) and heterotrophic microbial respiration (R_H).

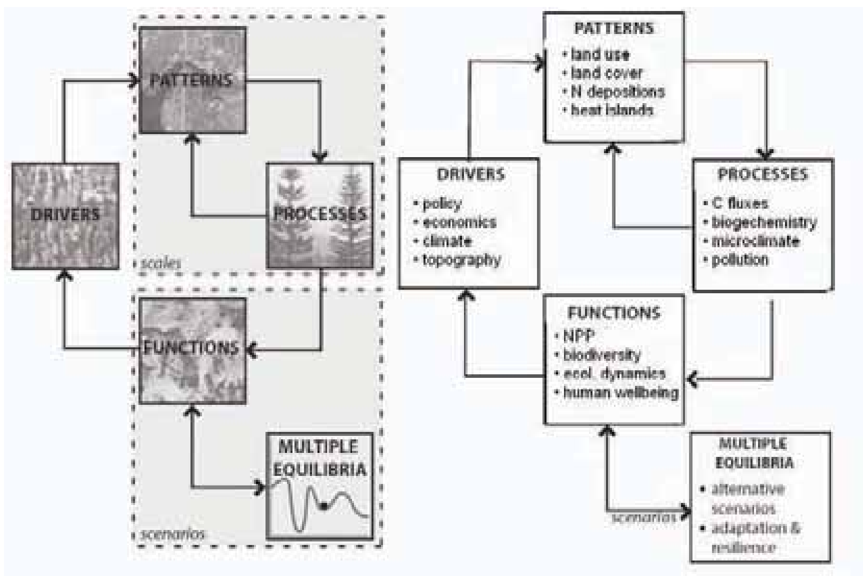
$$NEP = GPP - (R_H + R_A) \qquad (1)$$

NEP can be directly measured in the field through biometric or micro-meteorological methods. Positive NEP values indicate that an ecosystem is a net sink of atmospheric CO_2, while negative NEP indicates that an ecosystem is emitting more CO_2 through respiration processes to the atmosphere than it is removing through photosynthesis. NEP differs from net primary productivity (NPP) in that NEP accounts for total ecosystem respiration process while NPP only accounts for live plant respiration ($NPP = GPP - R_A$). The carbon fluxes of vegetated terrestrial areas vary on short time scales due to weather conditions or seasonal changes and on longer time scales due to changes in forest structure (*i.e.* carbon stocks). Urban environments have been estimated to be significant sources of global atmospheric CO_2 emissions, with some studies suggesting that up to 80% of total emissions originate in urban areas (Churkina 2008). Anthropogenic carbon emissions through activities such as energy generation or transportation are fluxes to the atmosphere, which affect the quantity of carbon in the atmosphere and subsequently interact with vegetation.

3. LINKING URBAN PATTERNS TO CARBON FLUXES

To understand mechanisms linking urban patterns and carbon fluxes we build on theories of complex coupled human-natural systems (Figure 1). In human dominated ecosystems, human and ecological factors (such as demographics and economics coupled with geomorphology and climate) affect human and ecological patterns and processes at multiple scales. Ultimately these interactions affect ecosystem function (both biotic integrity and human well-being) and they can generate system shifts under alternative scenarios. Changes in ecosystem functions feed back on human activities and well-being.

FIGURE 1
Conceptual Framework of Coupled Human-Natural Systems



Urbanization can fundamentally alter carbon fluxes and NEP through changes in land cover and creation of impervious surfaces, filling of wetlands, landscape fragmentation, and the application of fertilizers. Ecosystem productivity also should vary in time at a given site as urbanization proceeds, analogous to disturbance and succession in non-urban ecosystems. Following land conversion (initial disturbance), net biomass accrual should be maximal according to theory (Odum 1969), slowing as vegetation reaches maturity. Furthermore, waste emissions from human activities affect vegetation function and health and hence NEP (*e.g.*, Gregg et al. 2003; Shen et al. 2008).

Research Questions and Hypotheses

We have developed a framework to empirically test hypotheses of how alternative development patterns may impose different carbon signatures (spatial and temporal changes in stocks and fluxes) and how these signatures may in turn influence patterns of urbanization (Figure 1). This framework can be applied to questions such as:

- 1. How do urban patterns affect carbon fluxes and stocks along gradients of urbanization?
- 2. How do changes in ecosystem function feed back onto urbanization patterns?
- 3. What are the uncertainties, lags, legacies, and feedbacks associated with urban land use and infrastructure decisions on carbon fluxes and stocks?
- 4. How will the interactions between urbanization patterns and carbon processes evolve under future scenarios?

In this paper we limit our discussion to two core hypotheses:

HYPOTHESIS 1: Variability in ecosystem productivity across a gradient of urbanization is controlled by the composition and heterogeneity of the urban landscape.

HYPOTHESIS 2: Carbon fluxes vary across an urban-to-rural gradient in relation to land uses through changes in land cover, emissions of pollutants, and modification of the microclimate. This relationship is not linear due to the differential effects of patterns of urbanization on carbon emissions, sequestration, and accumulation in soil and vegetation.

Mechanisms Affecting Carbon Stocks and Fluxes Along an Urban Gradient

Our hypotheses about the variability of carbon stocks and fluxes along an urban gradient are grounded on mechanisms known to affect carbon stocks and fluxes (Canadell 2003). The mechanisms influencing carbon stocks (pools of C) can be distinct from those influencing C fluxes (rates of exchange). We identify four key mechanisms that affect change in carbon stocks and fluxes along a gradient of urbanization in temperate ecosystems: land use, organic inputs, temperature, and nitrogen fertilization. There is increasing evidence that alternative urban activities and infrastructure do mediate the impact of the patterns of urbanization on carbon fluxes and stocks (Kaye et al. 2006), Hutyra et al. 2011; Churkina et al. 2010). Here we do not represent these and assume alternative patterns of urbanization imply alternative types of infrastructure. A discussion of the role of infrastructure is in Alberti and Hutyra (Forthcoming).

Carbon fluxes include both positive (uptake: photosynthesis) and negative (loss: respiration, combustion) exchange processes. We hypothesize that the rates of per unit biomass carbon uptake will be higher in the urban core due to favorable growing conditions (human watering, fertilizer, pruning, replacements of landscaping vegetation in the Seattle region). C losses from ecosystem respiration (R_H) in urban core will be higher per unit mass, due to increased temperatures and adequate moisture, but the removal of organic inputs (leaf litter and woody debris) will reduce the amount of substrate (stock) for decomposition and result in an overall decrease in R_H. Higher urban concentrations of ozone will also dampen C uptake rates (GPP), but increased atmospheric CO_2 concentrations will positively impact GPP.

Carbon stocks within vegetation will be higher as we move away from the urban core, but we hypothesize that the changes will be non-linear. In addition, C fluxes typically respond and change on much shorter time scales (e.g. hours) than C stock (results of long-term changes in fluxes, respond on the time scale of years). Urban carbon stocks will be lowest at the urban core due to a replacement of potential growing space with buildings and pavement. Organic detrital C stocks are kept artificially low in urban areas through leaf and debris collection and removal, but the fluxes (input rates) would be expected to increase linearly across the urban to rural gradient (directly proportional to biomass and leaf area). The amount of C in vegetative biomass (and soils) is expected to increase with decreased development intensity, but fluxes (per unit mass) might be expected to decrease with decreasing temperatures and decreased nitrogen and CO_2 fertilization.

It is worth noting that these hypothesized relationships have been partially tested, but our understanding is incomplete and we expect mechanistic difference by biome. Urban regions are rapidly expanding and are in many respects a harbinger of broader future global change. Integrated measurements and models of these mechanisms are needed to advance viable scenarios for net emissions reduction.

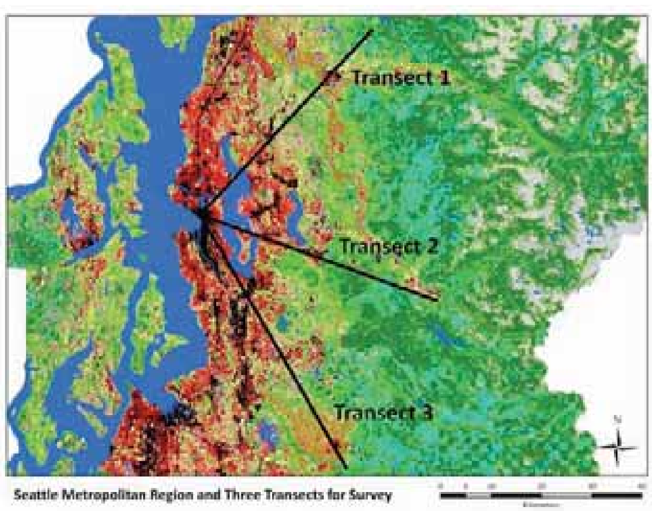
4. RESEARCH METHODS

To test our methodological framework and better refine our hypotheses, we have begun efforts in the Seattle, WA region to merge remote sensing and ground-based observations to determine the variability in ecosystem productivity across a gradient of urbanization and relate it to landscape structure and processes driven by urbanization. Land cover data provide information on the physical patterns and land use data provide information about the functional use of the land. We use remote sensing-based land-cover classifications to characterize changes in urbanization in the Seattle region. We have produced a systematic classification of 30-m resolution remote-sensing images for the Central Puget Sound for five time steps (Landsat TM 1986, 1991, 1993, 1995, 1999, 2002, and 2007) (Alberti et al. 2004). Parcel-level GIS data and road networks data was obtained from the counties, and attribute data including land use, building units, and year built of the existing development are derived from the assessor records (UERL 2006).

An initial field survey was conducted across the Seattle, WA metropolitan statistical area to characterize vegetative carbon stocks with respect to land cover. The sample transects radiated from the central Seattle urban core (origin UTM Zone 10N: 549518E, 5273765N; following bearings of 43º, 110º, and 300º and extended for ~ 50km) and we applied a stratified random sampling approach to survey 154 plots across five land cover classes (Figure 2). Each plot had a sample radius of 15 meters. The land cover classes included: high urban, medium urban, low urban, mixed forest, and coniferous forest. See Hutyra et al. (2011) for additional methodological details.

Our initial focus was on aboveground biomass (plants with a diameter greater than 5-cm at a height of 1.3 m, residential yards, and dead woody debris (diameter greater than 10 cm and length greater than 1 m)). Vegetation carbon stocks were quantified through biometric methods (Fahey and Knapp 2007). Using plant-diameter measurements and allometric equations (species specific where possible), we estimated carbon stocks in the live and dead carbon pools. In the future we plan to add plant photosynthesis and soil respiration measurements, which will supplement the plot surveys to provide information about instantaneous flux responses. Soil carbon stocks will be estimated through core samples and measurements of depth of the litter layer.

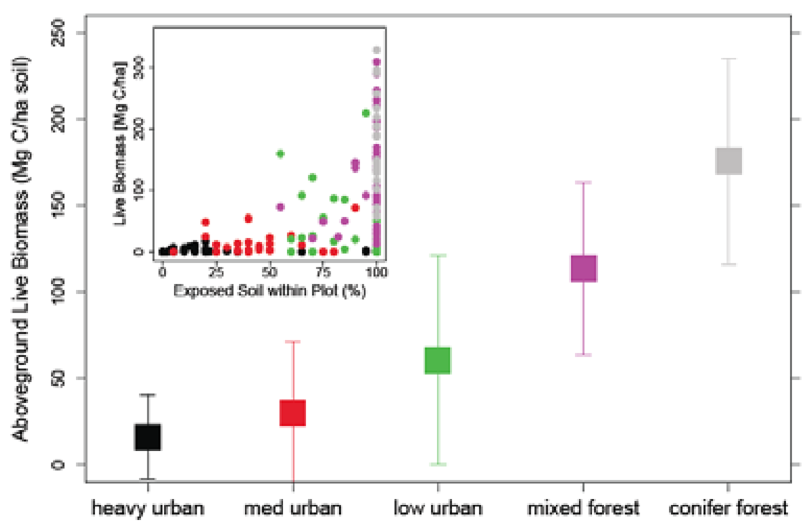
FIGURE 2 Three sample transects were established radiating outward from the Seattle, WA, USA urban core. Transects are overlaid on a 2002 land cover map of the region. Black, red, and pink colors denote high, medium, and low urban, respectively. Green tones denote vegetation.



5. URBAN VEGETATION RESULTS

Our initial observations will provide an empirical basis for refining our framework and hypotheses. We estimated that the mean aboveground live biomass across the Seattle urbanizing region was 89 ± 22 metric tons of carbon per hectare in 2002 (including both urban and forest area), with an additional 11.8 ± 4 Mg C ha^{-1} of coarse woody debris (CWD) biomass. The average biomass stored within forests was 140 ± 40 Mg C ha^{-1}. Within urban land covers: 18 ± 13.7 Mg C ha^{-1} (Hutyra et al. 2011). The distribution of carbon in live biomass across the land cover classes is shown in Figure 3. As expected, the forested plots have the highest carbon storage, but we found significant amount of carbon across the different developed sites and it varied considerably. These results are substantially larger than the 25.1 Mg C ha^{-1} (urban forest land only, including both above and belowground carbon) reported by Nowak and Crane (2002) for ten U.S. cities, and than the average of 53.5 Mg C ha^{-1} for all U.S. forests (urban and rural) reported by Birdsey and Heath (1995). While these results only provide data on a portion of the urban carbon cycle, they highlight the potential of vegetation to play an important role in offsetting emissions and planning future development.

FIGURE 3
Estimates of carbon stored in live vegetation across the Seattle metropolitan region (home to over 3 million people). Biomass values are expressed per soil area in the main plot and per total sample area (inset) to highlight the difference by land cover class and the potential opportunities for enhancement vegetative carbon sequestration.



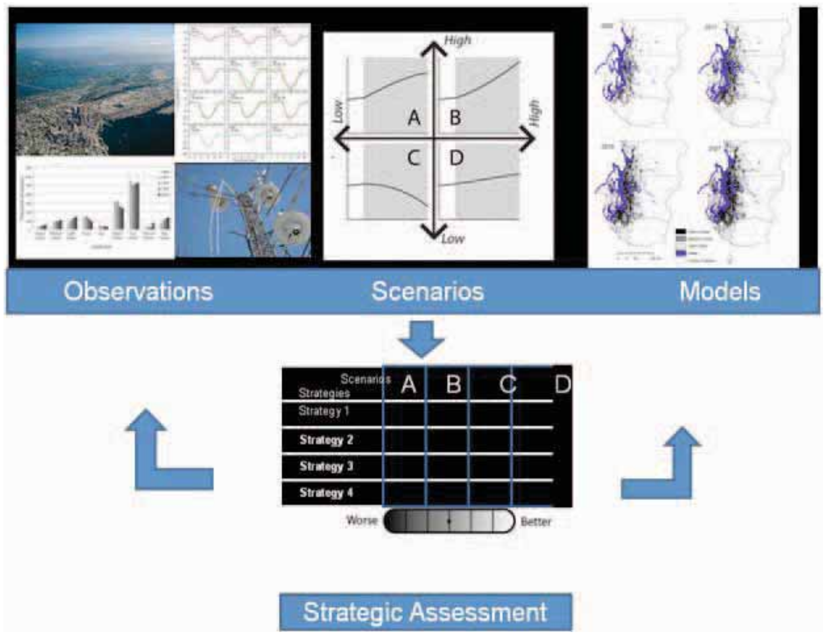
6. FUTURE SCENARIOS & NEXT STEPS

Advancing the study of coupled human-natural systems in urbanizing regions requires moving beyond idiosyncratic studies towards integrated, cross-regional comparisons (Grimm et al. 2008). The success of such studies depends on developing a robust comparative framework and common metrics and methods for identifying and testing hypotheses of similarities and differences in both urbanization patterns and mechanisms governing urban ecosystems dynamics. In our study we use a gradient approach and field observations to gain insights on the mechanisms that link urbanization patterns to carbon fluxes in metropolitan regions by focusing on vegetation dynamics.

Given biophysical and social influences on urbanization, carbon fluxes and ecosystem responses are likely to exhibit regional differences (Grimm et al. 2008). Both socio-demographic and socio-economic factors are key drivers of urbanization patterns, but biophysical factors such as climate and geomorphology also significantly influence these patterns. We expect that differences in socioeconomic and biophysical characteristics among the metropolitan regions will drive alternative carbon footprints and influence both the nature of the coupling and strength of feedbacks across a gradient of urbanization.

To build a robust planning strategy to reduce CO_2 emissions and test our hypotheses articulated here we are continuing our efforts to combine biophysical and social observations across multiple regions. Empirical data that accurately take into account the diverse sources and sinks of carbon in urban regions are critical to gain a mechanistic understanding of the urban carbon cycle, and to guide policy makers and planners in developing carbon-sensitive land use and transportation strategies. In the longer term, such data will provide the baseline for assessing the effectiveness of policies and define best development practices. Monitoring through new refined observations of land cover change and carbon fluxes, for example by installing flux towers across a gradient of urbanization, is critical to advance such strategies. In addition we will need to develop scenarios to explore the most divergent points of uncertainty and important trajectories of land use land cover change. Through a fusion of observations and increased mechanistic understanding, we can use scenarios as sets of hypotheses in order to run predictive models and explore alternative futures (Figure 4). For further discussion on the these hypotheses see: Alberti and Hutyra 2012 (Forthcoming).

FIGURE 4
Schematic for Linking Observations, Models and Scenarios for Strategic Carbon Assessment



Acknowledgements

This work has been supported by the Bullitt Foundation and NSF BE/CHN 0508002. Thanks to Michael Strohback and Bryan Yoon for assistance in the field.

References

Alberti, M. and L. Hutyra. 2012 (Forthcoming). Carbon signatures of development patterns along a gradient of urbanization. Chapter 12 in D.T. Robinson, D. G. Brown, N. French, and B. Reed (Eds) *Land Use and the Carbon Cycle Science and Applications in Coupled Natural-Human Systems*. Cambridge Press.

Alberti, M., Marzluff J.M., Shulenberger E., Bradley G., Ryan C., and C. Zumbrunnen. 2004. "Integrating humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems." *Bioscience*, 53: 1169–79.

Baker, L.A., Hartzheim P.M., Hobbie S.E., King J.Y., and K.C. Nelson. 2007. "Effect of Consumption Choices on Fluxes of Carbon, Nitrogen and Phosphorus through Households." *Urban Ecosystems* 10: 97–117.

Birdsey, R.A., and L.S. Heath. 1995. "Carbon Changes in U.S. Forests." In *Climate Change and the Productivity of America's Forests*, ed. Joyce, L.A. 56–70. USDA Forest Service General Technical Report RM 271, Fort Collins, CO.

Buyantuyev, A., and J. Wu. 2008. Forthcoming. "Evaluation of Urbanization Effects on Primary Production in Sonoran Desert Ecosystems using MODIS NDVI Data." *Remote Sensing of Environment*.

Canadell, J. G. 2003. "Global Carbon Project: Science Framework and Implementation." Earth System Science Partnership (IGBP, IHDP, WCRP, DIVERSITAS) Report No. 1; Global Carbon Project Report No. 1. Canberra. Global Carbon Project. http://www.GlobalCarbonProject.org.

Churkina G, Brown D.G., and G. Keoleian. 2010. "Carbon Stored in Human Settlements: The Conterminous United States." *Global Change Biology* 16: 135–43.

Churkina, G. 2008. "Modeling the Carbon Cycle of Urban Systems." *Ecological Modeling* 216: 107–13.

Gregg, J.W., Jones C.G., and Dawson T.E. 2003. "Urbanization Effects on Tree Growth in the Vicinity of New York City." *Nature* 424: 183–87.

Grimm, N.B., Foster D., Groffman P.M., Grove J.M., Hopkinson C.S., Nadelhoffer K.J., Pataki D.E., and D.P.C. Peters. 2008. "Land Change: Ecosystem Responses to Urbanization and Pollution across Climatic and Societal Gradients." *Frontiers in Ecology and the Environment* 6: 264–72.

Grimmond, C.S.B., King T.S. Cropley F.D., Nowak D.J., and C. Souch. 2002. "Local-Scale Fluxes of Carbon dioxide in Urban Environments: Methodological Challenges and Results from Chicago." *Environmental Pollution* 116: S243–54.

Gurney, K.R., Mendoza D.L., Zhou Y.Y., Fischer M.L., Miller C.C., Geethakumar S., and S.D. Du Can. 2009. "High Resolution Fossil Fuel Combustion Co2 Emission Fluxes for the United States." *Environmental Science and Technology* 43: 5535–41.

Hutyra, L., Yoon B., and M. Alberti. 2011. Forthcoming. "Terrestrial Carbon Stocks across a Gradient of Urbanization: A Study of the Seattle, WA Region." *Global Change Biology*.

Imhoff, M.A., Bounoua L., DeFries R., Lawrence W.T., Stutzer D., Tucker C.J., and T. Ricketts. 2004. "The Consequences of Urban Land Transformation on Net Primary Productivity in the United States." *Remote Sensing of Environment* 89: 434–43.

Kaye, J.P., P.M. Groffman, N.B. Grimm, L.A. Baker, and R.V. Pouyat. 2006. "A Distinct Urban Biogeochemistry?" *Trends in Ecology & Evolution* 21:192–99.

Odum, E.P. 1969. "The Strategy of Ecosystem Development." *Science* 164: 262–70.

Pataki, D., Fung A., Nowak D., McPherson E., Pouyat R., Golubiewski N., Kennedy C., Romero Lankao P., and E. Alig. 2007. "Human Settlements and the North American Carbon Cycle." In *State of the Carbon Cycle Report (SOCCR),* ed. J. David, chapter 14.

Pataki, D.E., Alig R.J., Fung, A.S., Golubiewski N.E., Kennedy C.A., McPherson E.G., Nowak D.J., Pouyat R.V., and P.R. Lankao. 2006. "Urban Ecosystems and the North American Carbon Cycle." *Global Change Biology*, 12 (11): 2092–102.

UNFPA (United Nations Population Fund). 2007. *United Nations: State of the World Population*.

Urban Ecology Research Laboratory. 2006. "Database for Land Cover Change Model." In *Biocomplexity I Final Report,* ed. Alberti, M., J. Marzluff, M. Handcock, P. Waddell. 2006. National Science Foundation.

CHAPTER 3

A Critical and Comparative Evaluation of Co_2 Emissions From National Building Stocks of Developed and Rapidly-Developing Countries — Case Studies of UK, USA, and India

Rajat Gupta* and Smita Chandiwala

1. INTRODUCTION

In 2002, buildings were responsible for 7.85Gt, or 33% of all energy-related CO_2 emissions worldwide (Price et al. 2006), and these emissions are expected to grow to 11Gt or 15.6Gt by 2030 (IPCC 2007), the two figures are based on different projected scenarios. In developed countries such as the United States and the United Kingdom, energy use in the building stock is responsible for about 50% of national CO_2 emissions (Mazria and Kershner 2008; DOE 2006; EPA 2003). Yet most efforts nationally and internationally have focused on improving the performance of new buildings (WEC 2004). The UK has set a target of making all new domestic buildings 'zero carbon' by 2016 and all new non-domestic buildings zero-carbon by 2019 (DCLG 2006). Similarly, in the US the Architecture 2030 campaign calls for the fossil-fuel reduction standard for all new buildings to be increased to 60% in 2010, 70% in 2015, 80% in 2020, 90% in 2025 and carbon neutral by 2030 (Mazria and Kershner 2008). Similarly, the 'Building Energy Code' in India is currently voluntary and applicable for new commercial buildings or building complexes that have a connected load of 500kW or greater, or a contract demand of 600KVA or greater (Bureau of Energy Efficiency 2006).

*Corresponding author: rgupta@brookes.ac.uk

Given that about two-thirds of existing buildings will be standing in 2050, targeting new buildings only limits the increase in CO_2 emissions. To reduce CO_2 emissions in the longer-term, the existing building stock needs to be targeted (Urge-Vorsatz et al. 2007). The problem with existing buildings is simple: they underperform in relation to current building standards because they were designed and built at a time when sustainability and energy efficiency were not the imperatives that they are today. To put this in context, a typical UK house built in 1910 emits in the region of eight tonnes of CO_2 per annum, and a house built in 1995, four tonnes per annum. The existing building stock in both developed and developing countries offers a sector where reductions in emissions could be achieved rapidly through technical, educational and other means, leading to more comfortable environment with lower fuel bills (Bordass et al. 2001).

According to the Fourth Assessment Report of the IPCC (2007), approximately 29% of CO_2 emissions can be saved economically, or at a net benefit to society, even at a carbon price of zero. The opportunity for very substantial investments into improving the existing building stock has opened up as the housing markets in the UK, USA and several other developed countries have gone into deep and prolonged recession. Mitigation measures in the residential and commercial sectors can save approximately 1.6 billion and 1.4 billion tons of CO_2 emissions respectively by 2020 (Urge-Vorsatz et al. 2007a). While the magnitude of these large potentials that can be captured has been known for decades, many of these energy efficiency possibilities have not been realized. This is because of certain characteristics of markets, user behaviour and a lack of critical evaluation of the available tools and models that could be used by planners, building designers and policy-makers to measure, benchmark, target, plan and monitor energy-related CO_2 emissions and forecast reductions from existing buildings.

This paper aims to address this gap by undertaking a critical and comparative evaluation of approaches and policies to measure, benchmark, reduce and manage CO_2 emissions from energy use in the existing building stock in developed and rapidly-developing countries using case studies of the UK, USA, and India. The specific objectives are as follows:

- Establish what tools, approaches and methodologies are available for measuring energy use and CO_2 emissions from existing buildings in UK, USA and India.
- Review and compare benchmarks of annual energy consumption intensities (kWh/m^2/year) and CO_2 emissions (kgCO_2/m^2/year) from buildings-in-use in the case study countries.
- Develop more rigorous standards for existing buildings (to reduce their energy consumption), which could be adopted by developed and rapidly-developing cities taking account of building type, local climate and occupancy.

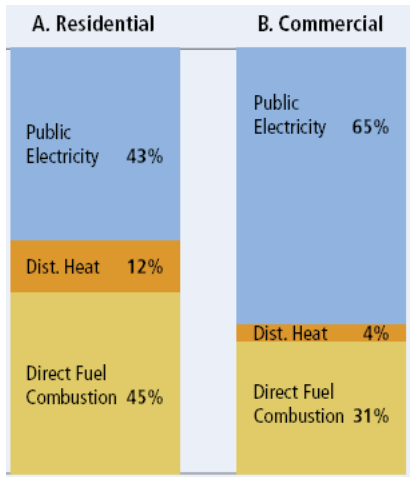
- Evaluate various strategies and measures available for maximizing CO_2 emission reductions in existing buildings (above 80% in developed countries) through improved energy-efficiency, low and zero carbon technologies, as well as non-technical solutions (education and awareness, behavioral change), and to identify barriers to their implementation.
- Recommend policy measures which would increase uptake of the selected CO_2 reduction strategies in existing buildings.

1.1 Overview Of Energy Use and CO_2 Emissions in the Global Building Stock

Globally, energy (delivered) use in the built environment, which encompasses *domestic (residential)* and *non-domestic buildings,* will grow by 31% over the next 20 years, at an average annual rate of 1.5%, according to International Energy Outlook (EIA 2006). In 2030, consumption attributed to domestic and non-domestic sectors (commercial) will be approximately 67% and 33% respectively. Industrial energy use is not considered as part of the buildings analysis in this paper. The growth in population, increasing demand for building services and comfort levels, together with the rise in time spent inside buildings, assure that the upward trend in energy demand will continue in the future. Economic, trading and population growth in rapidly-developing economies will intensify needs for education, health and other services, together with the consequential energy consumption. It is expected that energy consumption in the non-domestic building sector in developing countries will double in the next 25 years, with an annual average growth rate of 2.8% (Pe´rez-Lombard et al. 2008).

CO_2 emissions from the building sector are predominantly a function of energy consumption and may be either *direct* (on-site), such as emissions from fuels combustion, or *indirect*, such as emissions from electricity use and district heat consumption. More recently, studies are also including embodied energy of materials for building construction — e.g, cement or concrete. Certain energy end-use activities such as cooking, air-conditioning, space heating and refrigeration may generate either direct or indirect emissions depending on the technology used (Baumert et al. 2005). Broadly, emissions from buildings can be organized into three broad categories: *electricity use*, *direct fuel combustion*, and *district heating* (Figure 1).

FIGURE 1
CO_2 from Building Energy Use



Source: Baumert et al. 2005

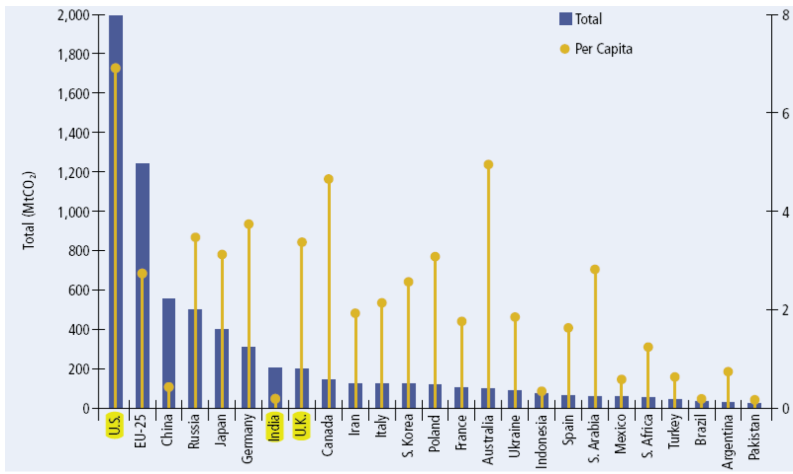
Electricity use includes lighting, appliance use, refrigeration, air conditioning, and to some extent, space heating and cooling. These activities account for 65% of commercial building emissions and 43% of residential building emissions (Figure 1). Globally, the building sector including residential and commercial is responsible for more electricity consumption — 42% — than any other sector.

Direct fuel combustion results primarily from space heating with modest contributions from food preparation (gas-driven cooking) as well as gas-driven air conditioning and refrigeration systems. This source accounts for 45% and 31% of emissions in residential and commercial buildings, respectively.

District heating includes centrally-operated heating (and sometimes cooling) systems that service entire cities or other large areas.

Emissions from the building sector vary widely by country in both absolute and per-capita terms (Figure 2), and depend greatly on the degree of electrification, level of urbanization, amount of building area per capita, prevailing climate, as well as national and local policies to promote efficiency.

FIGURE 2
CO_2 from Building Energy Use, Total and Per Capita in 2002: Top 25 Emitters



Source: IEA 2004a, 2004b

Within the building sector, it is important to distinguish between *domestic* (residential) and *non-domestic buildings*. The non-domestic (service) building sector, which covers all commercial and public buildings, includes many types of buildings (schools, restaurants, hotels, hospitals, museums, etc.) with a wide variety of uses and energy services (HVAC, domestic hot water (DHW), lighting, refrigeration, food preparation, etc.). The type of use and activities have a huge impact on the quality and quantity of energy services needed in non-domestic buildings. By and large, dwellings in developed countries use more energy than those in emerging economies and it is expected to continue growing due to the installation of new appliances (air conditioners, computers, etc.)

2. ENERGY USE AND CHARACTERISTICS OF EXISTING BUILDINGS IN UK, USA AND INDIA

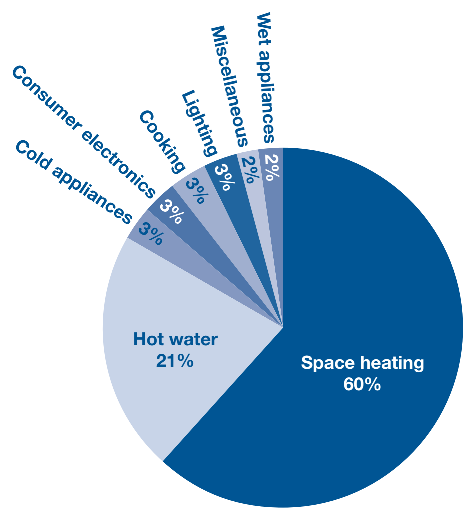
2.1 Existing Building Sector in the UK

Energy use in the buildings sector alone generates almost half of all CO_2 emissions in the UK — 27% from the 26.4 million residential dwellings, and 18% from the two million non-domestic buildings (including commercial, public sector, and industrial building use) (All Party Urban Development Group 2007; Pout and MacKenzie 2005). To assess the potential for CO_2 emissions reductions from the UK building stock, the energy performance and characteristics of domestic and non-domestic sectors should be characterized, as discussed in the following sub-sections.

2.1.1 Domestic Building Sector

In the UK, a major use of energy within the built environment is for heating. Gas currently meets more than two-thirds of this demand through the nationwide gas grid. Heating is a particularly important part of energy use within homes and hence a major contributor to CO_2 emissions from the domestic sector (Foresight 2008). As a guideline, household energy consumption is in the range of 21-22,000 kWh a year, for all energy use in the home, from all sources of fuel (Boardman 2007b, p. 4). Of this, roughly 60% is for space heating, 21% for hot water and 13% for lights and appliances (Figure 3).

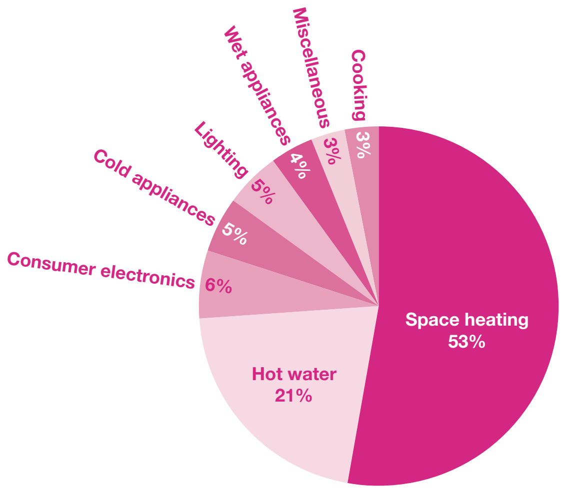
FIGURE 3
UK Household Energy Consumption by End Use



Source: DEFRA 2007; SDC 2006

Proportions of CO_2 emissions from various activities in housing are shown in Figure 4, which shows that the major portion of energy consumption is in space heating and hot water (81%). However, the proportion of CO_2 emissions from those uses is less (74%) due to the lower carbon content of gas compared to electricity. Over the long term, energy demand has grown fastest from appliances, with energy for heating remaining largely stable, although recent changes are much smaller (CLG 2006).

FIGURE 4
UK Household CO_2 Emissions by End Use

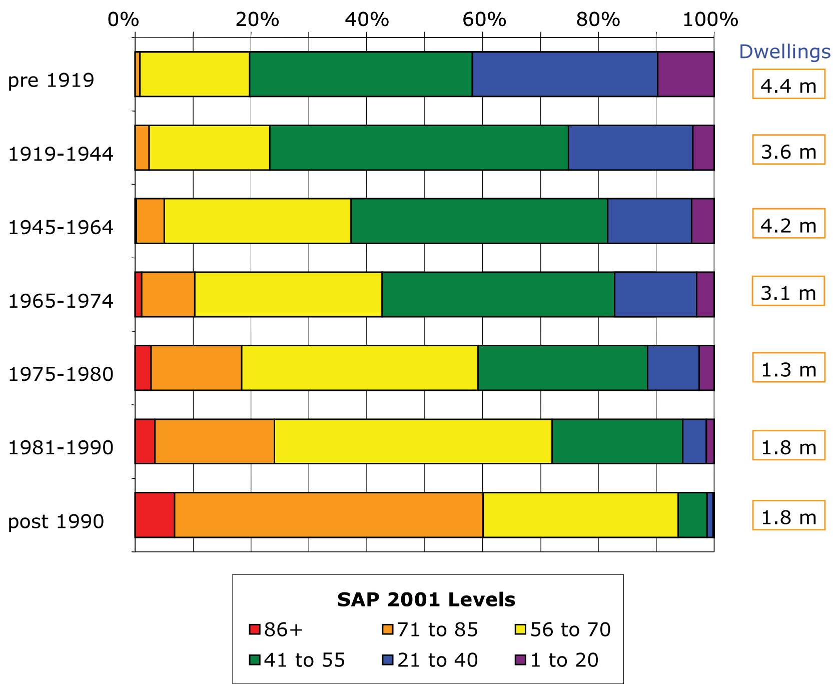


Source: DEFRA 2007; SDC 2006

Energy performance of domestic buildings in the UK is measured using the Standard Assessment Procedure (SAP), which measures the fuel efficiency of the heating systems and thermal efficiency of the building fabric i.e. how well it retains heat (BRE 2005). The average SAP of the 2004 stock was 52. Energy performance varies widely across the domestic stock. The factors that have the greatest correlation with energy performance of the existing stock are age and dwelling type/size. Modern properties are much more energy efficient and smaller properties suffer less heat loss. Apart from these more or less immutable factors, the quality and amount of insulation and efficiency of heating systems also affect energy performance (CLG 2006). Other factors that are taken into account in the SAP calculations include building shape, orientation, window sizes and distribution. The 2009 edition of the Standard Assessment Procedure (SAP 2009) was introduced in October 2010 (BRE 2010).

A step change in the energy efficiency of post-1990 stock, since implementation of Part L of the Building Regulations, has progressively raised the energy efficiency standards for new homes. Improvements in the energy performance of new build, combined with household improvements, have led to an increase in the average energy efficiency of the stock. Two-thirds of all properties have SAP values between 41 and 70. There is a clear trend of older properties having much lower energy performance: over 40% of properties built before 1919 have SAP values of less than 41 (Figure 5). By contrast, 60% of properties built since 1990 have SAP ratings above 70.

FIGURE 5
Profile of Energy Performance of Existing Domestic Stock in UK, 2004



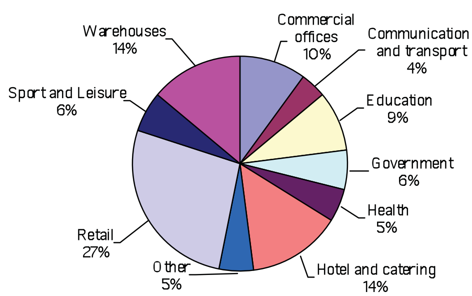
Source: CLG, 2006

The total energy consumption in the domestic stock also depends upon the number of households and population. Of the 26.4 million dwellings in the UK in 2006 (CLG 2008a), 31% consist of one-person households. This figure is projected to increase to 38% or nearly 10 million one-person households in 2026. Such a shift in household size would have significant implications for how energy is used in homes. At the same time, the UK population is expected to increase to 67 million by 2050 and net migration to the UK is projected to continue. The effect of this growth is compounded by declining household size – in 2002, the average household contained 2.3 people, and it is assumed that this will drop to 2.1 people per household (pph) by 2050. There has also been an increase in expectations of material comfort over the past century. Desired temperature levels within the home have increased from 12°C in 1970 to 18°C in 2002, with consequent impacts on energy consumption.

2.1.2 Non-domestic Building Sector

Non-domestic buildings (primarily commercial and public) account for about one-sixth of the UK's total CO_2 emissions and one-third of the building-related ones (Committee on Climate Change 2008). Figure 6 shows the split of CO_2 emissions within the non-domestic sector, which indicates that the retail sector is the major contributor, followed by hotels and catering and warehouses (Pout and MacKenzie 2005).

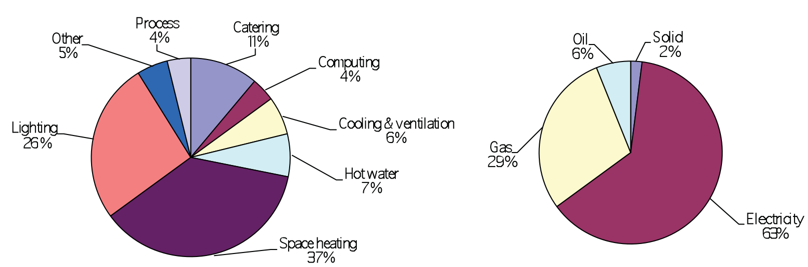
FIGURE 6
UK Non-domestic CO_2 Emissions by Sub-sector in 2002



(*Source:* Pout and MacKenzie 2005)

Figure 7 shows the breakdown of CO_2 emissions by end use and by fuel type in the non-domestic sector. In terms of end use, it is clear that heating contributes the most at 37%, followed by lighting at 26%. In terms of emissions by fuel type, electricity contributes the most, followed by gas, since the carbon emission factor of electricity in the UK (1kWh of grid electricity = 0.556 kg CO_2) is about three times more that gas (1kWh of natural gas = 0.194 kg CO_2) (Pout and MacKenzie 2005).

FIGURE 7
UK Non-domestic CO_2 Emissions by Sub-sector in 2002



(*Source:* Pout and MacKenzie 2005)

Accurate data on total energy use in the non-domestic stock are not available, but estimates suggest that electricity consumption amounted to about 95GWh in 2004 and gas consumption to about 85GWh (Foresight 2008). Over 1990-2006, CO_2 emissions from commercial buildings grew by 4%. This was primarily due to a 6% rise in indirect (electricity-related) emissions, with electricity demand growth more than offsetting the declining carbon intensity of electricity. Public sector emissions fell 26%, wherein direct emissions fell due to energy efficiency improvements in heating and a switch to less carbon-intensive fossil fuels. Indirect emissions fell as the declining carbon intensity of electricity more than offset rising electricity demand (Committee on Climate Change 2008).

The total floor space of commercial and industrial bulk class properties in England and Wales was 597 million square meters in 2007, 6% more than in 1998 (Foresight, 2008). Although there is a statistical evidence base covering all recorded property types, drawn from the Valuation Office Agency database (Ravetz 2008), this covers hereditaments, floor spaces and rateable values; but not conditions, construction or other finer detail. A major effort was made by the then Global Atmospheric Division of DETR, to develop a national Non-Domestic Building Stock (NDBS) database (Bruhns et al. 2000). One result was the National Non-domestic Buildings Energy and Emissions Model (N-DEEM), which was used to model energy policy impacts (Pout, 2000). There may be more activity on this front in the future, as the energy performance of new and existing property is now emerging as a priority (CLG and UKGBC 2007). The non-domestic stock is somewhat more modern than the housing stock. Nevertheless, as seen in Figure 8, just over half of all commercial and industrial properties were built before 1940 and only 9% after 1990 (CLG 2005a; CLG 2005b). Just over a quarter of commercial building space by area was built before 1940 and only 15% since 1990 (Figure 9).

FIGURE 8
Age Profile Hereditaments on the Non-domestic Sector by Bulk Class

Source: Foresight 2008

2.1.3 Programmes for Achieving CO_2 Reductions from the Existing Building Sector in the UK

The European Commission is providing a complex framework for carbon reductions in the domestic sector — the requirement is to reduce CO_2 emissions by 20% and to have 20% of all energy from renewable sources, both by 2020, for the whole of Europe (Boardman 2007b). In line with this, the National Energy Efficiency Action Plan (NEEAP) set a target to reduce emissions from the UK's residential housing stock to 107.43MtCO_2 (a 31% reduction) by 2020 (DEFRA 2007). In February 2009, the UK Government launched a consultation on the *Heat and Energy Saving Strategy* (HESS), which sets out an aim for emissions from existing homes to be approaching zero by 2050 (DECC 2009c) in order for the UK to achieve its ambitious target of an 80% cut in emissions by 2050. Figure 9 summarizes the CO_2 emissions saved as part of these targets and programmes discussed.

FIGURE 9
Summary of UK Residential Sector Emissions Targets (MtCO2e)

Year	UK residential sector greenhouse gas emissions	UK residential sector CO_2 emissions
1990 baseline	45.8	42.4
2004 emissions	43.7	41.7
Targets[20]		
2008-12 (Kyoto)	40.1	n/a
2010 (CCP 2006)	38.6	37.6
2010 (NEEAP)	n/a	37.7
2010 (Gov target)	n/a	33.9
2016 (NEEAP)	n/a	33.1
2020 (NEEAP)	n/a	29.3
2020 (UK Climate Change Bill)	n/a	28.8 – 31.4
2050 (UK Climate Change Bill)	n/a	17
2050 (80% cut)	n/a	8.5

13 HM Treasury (2007). 14 International Symposium on the Stabilisation of greenhouse gas concentrations, Hadley Centre, 2005. 15 See, for example, Höhne, Phylipsen and Moltmann (2007). 16 RCEP (2000). 17 Defra (2006). 18 Defra (2007a); Defra's NEEAP covers energy efficiency measures, renewables and carbon emissions. 19 This figure is calculated on the current basis that international aviation and shipping are not incorporated into the targets. 20 Statutory residential sector targets or proportional allocations of wider targets.

Source: Centre for Sustainable Energy et al. 2006

To support HESS, the Government has set out the following key policy proposals:

- Provide the capacity to deliver comprehensive, whole-house solutions to 400,000 homes a year by 2015.
- By 2020, extend the delivery of whole-house solutions to approximately 7 million homes across the UK.
- Be on the way to making cost-effective energy efficiency measures available to all households by 2030.

These new ways of using energy in UK homes require a new approach to delivering the policies. The current delivery model, the Carbon Emissions Reduction Target (CERT) has seen energy suppliers under an obligation set by the Government to achieve certain emissions reductions (DECC 2009a). However, beyond this a more coordinated, community-based approach is used, working door-to-door and street-to-street to cover the needs of the whole house. The proposed new Community Energy Savings Programme (CESP), to be launched this year, will be a pilot for this more coordinated approach (DECC 2009b).

In the meantime, the following policy drivers continue to target energy use in UK homes (CLG 2006). The Government already has a legal obligation to ensure that people are not living in fuel poverty[1] by 2016, which is caused by a combination of poorly insulated, energy inefficient housing and low incomes. There were 3.5 million households in fuel poverty in 2006 and this figure increased to 5.5 million in 2009 (DECC,2011; Fuel Poverty Advisory Group 2008). Clearly, cutting CO_2 emissions through energy efficiency in UK homes can help in tackling fuel poverty, a long-standing problem for vulnerable groups in UK especially the elderly.

- *Decent Homes:* The Government's aim is to make all council and housing association housing decent by 2010 by improving the condition of an existing home to one that is warm, weatherproof and with reasonably modern facilities. It is not intended specifically to improve energy efficiency but, by including a thermal comfort criterion, it is expected to have a significant effect on the energy performance of those homes. In 2006, 37% of all housing was defined as 'non-decent' according to current standards (Foresight 2008).
- *Warm Front:* Government's main grant-funded programme for tackling fuel poverty, launched in June 2000. The scheme fits packages of measures including insulation and heating systems. Grants of up to £2,700 are offered for families and the disabled and a grant of up to £4,000 where the work approved is

[1] A household is in fuel poverty if in order to maintain a satisfactory heating regime it would be required to spend more than 10% of its income (including Housing Benefit or Income Support for Mortgage Interest) on all household fuel use.

installation of an oil-fired central heating system. Carbon emission reductions under Warm Front and other fuel poverty programmes are expected to be 0.4MtC a year by 2010;

- *Energy Performance Certificates (EPCs)* which are required on sale or rent of buildings. They give potential buyers/tenants information on the current performance of a house and its cost-effective potential, setting out the cost-effective measures relevant to the property;
- *Building Regulations:* If building work is being carried out on existing buildings, building regulations are likely to apply. This covers work from building an extension to replacing windows or the boiler. Part L of the building regulations sets standards related to the conservation of fuel and power.

The key policy affecting energy and CO_2 performance of non-domestic buildings is the Energy Performance of Buildings Directive (EPBD), part of European legislation that all member states must adopt. Measures set out by the Directive include the following (CLG 2008c):

- Introducing energy performance certificates (EPCs);
- Requiring public buildings to display energy certificates (DECs); and
- Requiring inspections for air conditioning systems.

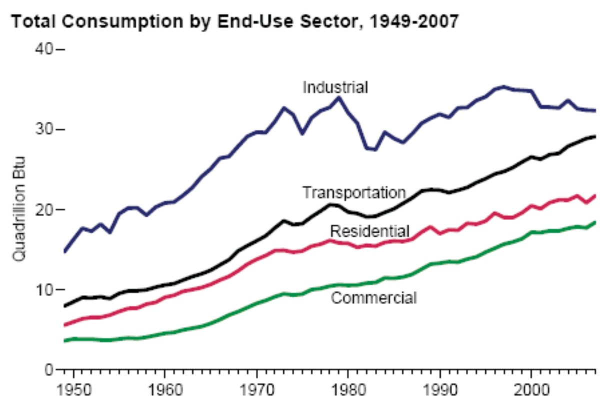
Under the Directive, since October 2008 all buildings — homes, commercial and public buildings — when sold, built or rented require an Energy Performance Certificate (EPC). The certificate provides energy efficiency ratings on a scale from A to G and recommendations for improvement. The ratings are standard, so that energy efficiency can easily be compared across different buildings of similar type (CLG 2008c). Since October 2008 Display Energy Certificates (DECs) are also required for larger public buildings over $1000m^2$, so that everyone can see how efficiently public buildings are using their energy. It is widely known that there is a gap between buildings' energy performance by design (EPCs) and how they actually operate (DECs). Therefore, both EPCs and DECs are needed in order to have a holistic picture of a building's energy performance (CLG 2008b).

On 19 May 2010, a recast of the Energy Performance of Buildings Directive was adopted by the European Parliament and the Council of the European Union in order to strengthen the energy performance requirements and to clarify and streamline some of the provisions from the 2002 Directive it replaces. One of the main highlights of the Recast EPBD for existing buildings is that member states shall develop policies and take measures (such as targets) in order to stimulate the transformation of buildings that are refurbished into very low energy buildings (European Commission, 2010).

2.2 Existing Building Sector in the USA

Energy use in the United States (US) rose by almost 50% from 1970 to 2007. This growth has come through oil, coal and nuclear energy, although the contribution of gas has not changed much (EIA 2008b). Oil was the largest source of energy in 1970 and still is. Renewable energy provided 6% of energy needs in both 1970 and 2005. The decreasing importance of natural gas and the increasing use of coal in the energy mix (especially for electricity generation) is one of the factors underlying the increasing CO_2 emissions (Hillman et al. 2007). This is in marked contrast to the UK, where the use of coal, especially in power stations, has dropped sharply and its replacement with natural gas has consequently reduced CO_2 emissions. Changes in the proportion of total (final) energy used by different sectors of the economy since 1970 are shown in Figure 10. Although energy use by industry has become less important, commercial energy use has risen by more than half and residential energy use has gone up by a sixth (EIA 2008b).

FIGURE 10
Changes in the Proportion of Final Energy Demand by End-Use Sector from 1949 to 2007.



Source: EIA 2008b

Data from the US Energy Information Administration (EIA) distributes the various elements of the building sector into several sectors, i.e. industry, commercial, residential, transportation and so on. The proportion of final energy demand by the different sectors in 2007 was:

- Residential: 21%
- Commercial: 18%
- Transportation: 29%
- Industrial: 32%

To determine the real energy impact of buildings, *Architecture 2030* has combined these various elements into a single sector called Buildings (Mazria and Kershner 2008; Mazria and Kershner 2009)[2]. Using data drawn from the EIA, it is seen that buildings are responsible for almost half (48%) of all energy consumption and GHG emissions annually; globally the percentage is even greater. Seventy-six percent (76%) of all power plant-generated electricity is used just to operate buildings. The annual embodied energy of building materials and the energy used to construct buildings is estimated at 1.146 MBtu/sf of building for new construction and half of this for renovation. Residential, commercial and industrial building operations consume 76% of total US electricity generation (Mazria and Kershner 2008).

When building-related energy use (residential, commercial and industry building use) is split by end use, it is seen that space heating and space cooling are the major energy requirements (Table 1). However lighting becomes as significant as space heating when CO_2 emissions by end-use are presented, since electricity has a large CO_2 emission factor than gas which is typically used for space heating (National Energy Technology Laboratory 2008).

TABLE 1
Primary Energy and CO_2 Emissions in the US Building Stock

End Use	Residential		Commercial		Total Building Stock	
	Primary Energy %	CO_2 Emissions %	Primary Energy %	CO_2 Emissions %	Primary Energy %	CO_2 Emissions %
Space heating	26.4	26	12	12	19.8	20
Space cooling	13	13	13	12	17.7	13
Water heating	12.5	12	6	6	9.6	9
Lighting	11.6	12	25	25	7.8	19
Cooking	4.7	5	2	2	3.3	3
Wet clean	6.2	6	—	—	3.4	3
Refrigeration	7.2	7	4	4	5.8	6
Electronics	8.1	8	7	8	2.8	8
Computers	1.0	1	4	4	2.3	2
Other	3.6	4	13	13	8.5	8
Adjust to SEDS	5.7	6	7	8	6.3	6
Ventilation	-	-	7	6	12.7	3

[2] To create a US Building Sector percentage for the year 2000, the Residential buildings (operations) sector (20.4 QBtu), Commercial buildings (operations) sector (17.2 QBtu), Industrial sector - buildings operations (2.0 QBtu) and the Industrial sector — annual building construction and materials embodied energy estimate (8.57 QBtu) were combined. Total annual 2000 Building Sector consumption was 48.17 QBtu and the total annual 2000 US Energy consumption was 99.38 QBtu. (Source: US Energy Information Administration annual energy review)

2.2.1 Residential Sector

Overall energy use in the residential sector has increased since 1970. Currently, the residential sector in the U.S. uses approximately 21 EJ (20 Quads) of site energy per year; this amounts to approximately 21% of all energy use in the nation (Parker 2009). In 2006, the residential sector consumed 37% of all electricity produced in the United States, making it the largest consuming sector of electricity (National Energy Technology Laboratory 2008). Average annual energy expenditures per household have increased by 20 percent from 1990. For every 1kWh used in the residential sector, another 2.18 kWh is needed to produce and deliver the electricity. The average price of electricity for residential consumers in 2006 was 10.4 cents per kWh (National Energy Technology Laboratory 2008).

Despite technological improvements in refrigerator, furnace efficiency and energy codes improving insulation, many American lifestyle changes have put higher demands on heating and cooling resources. The two-person household in a large home has become more common, as has central air conditioning: 23% of households had central air conditioning in 1978 while that figure rose to 55% by 2001. Also, miscellaneous electric end-uses in households since 2000 has been rapidly expanding, largely offsetting efficiency gains in the conventional end-uses of heating, cooling and water heating. Electricity is expected to be the fast growing site energy source for residential consumers averaging a 1% growth rate from 2006 to 2030. On-site renewable energy accounted for approximately 3% of all energy consumed in the residential sector. The majority of this energy was derived from wood combustion and was used for space heating.

Both the number and size of households influence total energy consumption in the residential sector. In spite of a fall in energy use in an average household, the strong increases in population and household numbers have resulted in a sector-wide increase. The US population has grown considerably and consistently over time: in 1970, the total was just over 200 million and it is shortly to hit 300 million (Hillman et al. 2007). The 1990 to 2000 population increase of 32.7 million at 13% towered over the average of 2.5% for other developed countries. In 2006, there were approximately 113 million households in the US and by 2030, there are expected to be 141 million households (National Energy Technology Laboratory 2008). At the same time, the average size of homes built in the United States has increased significantly, from 139m^2 in 1970 to 214m^2 in 2005 (Parker 2009). Recent electricity shortages in California, growing U.S. dependence on foreign energy supplies with highly volatile oil prices and the greatly expanding threat of global warming underscore the critical need to address the efficiency of US homes. Since the twin energy crisis of the 1970s, first passive solar, followed by super insulation have provided increasingly refined means to improve the energy performance of existing housing.

2.2.2 Commercial Building Sector

The following pieces of information give some insight into general trends in the commercial sector (National Energy Technology Laboratory 2008):

- Floor space devoted to commercial activity totalled 74.8 billion square feet in 2006. Commercial floor space is expected to reach 100.8 billion square feet by 2030.
- In 2006, lighting used 24.8% of primary energy attributed to the commercial sector and produced 25% of CO_2 emissions. This is approximately twice the energy used and emissions produced by space cooling.
- Lighting accounts for 42% of a commercial building's cooling load.
- In 2003, the most energy-intensive buildings were those related to food sales using 535.5 thousand Btu per square foot. The building type with the lowest energy intensity (excluding vacant buildings) was religious worship buildings using 77.0 Btu per square foot.
- Electricity accounted for 74% of all energy expenditures in the commercial sector. About 80% of all CO_2 attributed to the commercial sector comes from electricity consumption.
- The average price of electricity for a commercial consumer in 2006 was 9.5 cents per kWh.
- In 2003, buildings devoted to office space consumed 19% of primary energy attributable to commercial buildings, the most of any building type.

2.2.3 Programmes for Achieving CO_2 Reductions from Existing Building Stock

According to Mazria and Kershner (2008, 2009), the total US building stock equals approximately 300 billion square feet, of which approximately 1.75 billion square feet of buildings is pulled down, 5 billion square feet renovated and 5 billion square feet built annually. This means by 2035, approximately three-quarters (75%) of the built environment will be either new or renovated. Clearly, this transformation over the next 30 years represents a huge opportunity, and immediate action in the building sector is essential if we are to avoid hazardous climate change. To accomplish this, *Architecture 2030* issued the *2030 Challenge* calling for all new buildings and renovations to be designed so as to reduce their fossil-fuel, greenhouse-gas-emitting (CO_2) energy consumption by 30% below that required by the latest IECC 2006 and ASHRAE 90.1-2004 code standards, incrementally increasing the reductions to carbon neutral by 2030. Apart from improving the fossil-fuel reduction standard of new buildings incrementally every 5 years, *2030 Challenge* calls for an equal amount of existing building area to be renovated annually to meet a

GHG-emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type (Mazria and Kershner 2008).

In addition, there are a range of programs and organizations that are working to increase the energy efficiency of existing buildings in the US, as follows:

- *Building America* is a ten-year-old industry-driven research program, sponsored by the U.S. Department of Energy. The program has produced new homes on a community scale that use on average 40% to 100% less source energy. The program also increases the energy efficiency of existing homes by 20-30% (DoE 2004). Lessons learned by one builder are rapidly shared with other builders throughout the Building America community leading to improved building performance at no added cost.
- The ENERGY STAR® program was established by the U.S. Environmental Protection Agency (EPA) in 1992 for energy-efficient computers. The ENERGY STAR program works with manufacturers to promote existing energy-efficient products and develop new ones. Manufacturers can affix an easily visible label to products that meet Energy Star minimum standards (EPA 2003). The program has been a success and extended to include numerous other electrical appliances such as refrigerators, TVs etc. as well as buildings.
- The *ENERGY STAR Building Program* is the most widely used building energy label for existing buildings in the U.S. Developed by the EPA, it makes the energy performance rating available to users through password-protected accounts in a web-based tool called Portfolio Manager.

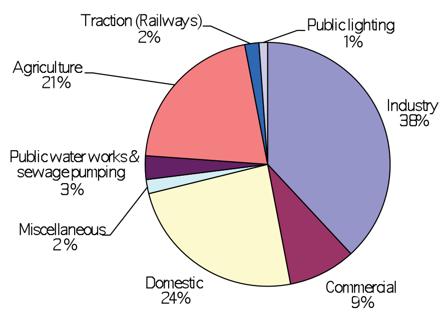
2.3 Existing Building Sector in India

India has emerged, both economically and politically, as one of the key global players. It is already the world's third largest economy growing recently at an average of 8.5% a year, and currently ranks sixth in the world in terms of primary energy demand. Its population has increased from 560 million in 1971 to 1,150 million in 2009, and is expected to be the world's most populous country by 2035 (Planning Commission 2005). The economy is shifting towards services located in urban centres with a growing upwardly mobile middle class. The construction industry in India is growing annually at a rate of 9.2% compared to the global average of 5.5%. It is predicted that by 2020 about 40% of India's population will be living in cities, as against 28% today (McNeil et al. 2008).

As a result of the growing economy and rapid urbanization, India has been witnessing continued growth in energy consumption. This trend has already begun to strain the power sector with energy shortages. The Central Electricity Authority (CEA) has estimated that the country is currently facing electricity shortage of 9.9% and peak demand shortage of 16.6% (CEA 2009). There are varied energy consumption patterns in different zones in India. The economically prosperous states of Gujarat, Punjab, Maharashtra, etc., show a high-energy consumption pattern. Per capita electricity consumption stood highest in Punjab (861kWh), followed by Gujarat (724 kWh) and Maharashtra (594kWh) against the national average of 360kWh (Statistical Abstract 2001). The poor regions of the Northeast, on the other hand, have a very low consumption of energy ranging between 75 and 185kWh, much lower than the national average.

The building sector in India is currently the second largest consumer of energy, and building energy use is increasing by over 9% annually, which greatly outpaces the national energy growth rate of 4.3% (USAID and LBNL 2006). Figure 11 shows the electricity consumption of various sectors in India (CEA, 2009).

FIGURE 11
Electricity Consumption by Sector in India



Source: CEA 2009

Since the building sector (domestic and commercial) accounts for approximately 33% of electricity consumption and is the fastest growing sector, it is critical that policies and measures are put in place to improve energy efficiency in both new construction as well as existing buildings. In fact it is estimated that 70% of building stock in the year 2030 is yet to come up in the country - a situation that is fundamentally different from developed countries such as the UK and US (Kumar et al. 2010).

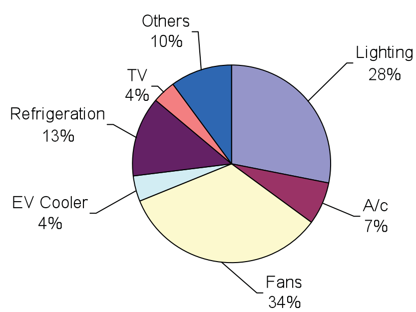
2.3.1 Residential Building Sector

Residential energy consumption (excluding traditional biomass) per capita rose the fastest in India, compared to China and the US (CMIE 2001; Reddy and Balachandra 2006). A switch from traditional biomass to modern fuels, and the increased use of modern fuels by an expanding urban population are driving factors behind this increase (Planning Commission 2005).

In developing countries such as India, it is important to divide households into rural and urban locales due to the different energy consumption patterns found in these locations. Disparities in household energy use exist between rural and urban populations and also between high- and low-income groups. In rural areas, traditional fuels, such as fuelwood, charcoal and agricultural waste, constitute a major portion of total household energy consumption, while in urban areas households use kerosene, electricity and LPG (Reddy and Balachandra 2006). According to analysis by LBNL, electricity consumption per urban household will increase from 908kWh in 2000 to 2972kWh in 2020 (LBNL 2009).

The type of end uses for energy consumption in urban residential buildings is shown in Figure 12. Lighting accounts for 28% and air conditioning for 7% of the total electricity consumed in the sector. Approximately 13% of the electricity consumed is in refrigerators.

FIGURE 12
Energy Consumption in the Indian Residential Sector, 116 Billion Units



Source: Bureau of Energy Efficiency 2006b

Energy use for air conditioning is a growing concern, as the rising middle class in India is in the process of making the transition into an energy-intensive way of life. Their new lifestyle aspiration for "air conditioned comfort", being met readily by what is now on offer off the shelf from the air conditioning industry, will become the largest cause of and contributor to increased energy consumption. The challenge and the opportunity of this transitional situation is to find those alternatives to meet legitimate aspirations for better comfort that are inherently less capital intensive as well as less energy intensive.

2.3.2 Commercial Building Sector

Electricity is a major energy form used in the commercial sector in India. Electricity use in this sector has been growing at about 11-12% annually, which is much faster than the average electricity growth rate of about 5-6% in the economy (Bureau of Energy Efficiency 2006b). Approximately 60% of electricity used in the commercial sector is consumed in lighting and 32% in space conditioning (as opposed to 7% in residential) (Bureau of Energy Efficiency 2006b). In other words, in the case of commercial buildings the threshold into air conditioning dependency has already been crossed and it would be very difficult to reverse the trend. Whereas in the case of residential buildings there is still the opportunity and potential of prevention (Lall 2008).

When this large urbanizing population crosses the threshold into a culture of air conditioned comfort in the home the impact on energy consumption will be severe. As one shifts from circulating fans and evaporative coolers to an air conditioner, the peak demand of electricity increases by six to ten times per unit of conditioned space— an increase of about 90 watts per square meter of conditioned space (Lall 2008).

This is even more important since it is estimated that while the building sector as a whole is poised to grow at a rate of 6.6% annually up to 2030, the commercial sector is currently growing at a rate of 9% per year. A recent study by McKinsey (2009) has estimated that by 2030 the built-up area is projected to increase from one billion square meters to four billion square meters for the commercial sector and from eight billion square meters to 37 billion square meters for the residential sector. Notably, 50% of the new construction is taking place in the public sector, which offers the Government a tremendous opportunity to lead by example in adopting energy-efficient practices.

2.3.3 Programmes for Improving Energy Efficiency in the Indian Building Stock

Building Energy Efficiency is emerging as a priority area for the Government of India considering the growth that is taking place in the Indian building sector. Not only will it help in the government's climate change mitigation efforts, but it will also help reduce the widening gap between the supply and demand of power.

In a major impetus to institutionalize energy efficiency in the country, the Government of India enacted the *Energy Conservation Act* in 2001. Under this Act, the government established the *Bureau of Energy Efficiency* (BEE) in March 2002, as a statutory authority under the Ministry of Power (MoP). The BEE's role is to enact and enforce energy efficiency policies through various regulatory and promotional measures. BEE estimates the potential for energy saving in the domestic/commercial building sector to be at least 20% (Bureau of Energy Efficiency 2006b). In conventional Indian buildings, energy consumption is

200kWh/m^2/year, which can be reduced to 120kWh/m^2/year by applications of energy efficient building techniques. BEE also developed an energy efficiency Action Plan which focused on various thrust areas which include Energy Efficiency in Commercial Buildings, Energy Conservation Building Code (ECBC), Energy Managers and Energy Auditors Certification Program, and others. These are discussed briefly as follows:

Energy Audit of Existing Buildings

BEE launched its first energy efficiency programme for existing buildings in 2002. Sample studies conducted in a few selected government buildings in Delhi under the programme, have identified energy savings potential of about 30% on average. In the following phase, 17 more buildings in Delhi have been audited. Similar initiatives are being considered for public and private buildings in the states, by the authorities as well as the building owners (USAID ECO-III project 2008a).

2003 Electricity Act

The Indian Parliament also passed the Electricity Act in 2003. It consolidated laws related to generation, transmission, distribution, trade and use of electricity (USAID and LBNL 2006). The Act also mandated the creation of regulatory commissions at the central, regional and state levels. As a consequence, the electric utility system is being unbundled, tariffs are being rationalized, and regulatory commissions are playing an active role in enforcement of bill collection and the promotion of DSM programs in some of the larger states. Under orders from the Maharashtra Electricity Regulatory Commission, for instance, utility companies in Maharashtra have initiated a lighting efficiency program in the residential sector, and the Bangalore Electricity Supply Company has initiated a similar program in Karnataka state.

Confederation of Indian Industry

Indian industry associations have played an important role in promoting energy efficiency. The Confederation of Indian Industry (CII) and Federation of Indian Chambers of Commerce and Industry (FICCI) are engaged in capacity building through the organization of training programs, workshops, conferences, exhibitions, poster displays, awards, and field visits.

- The Indian Green Business Centre is an example of an institution created by an industry association; CII jointly with the Andhra Pradesh government and with technical support from USAID set it up as a public private partnership. Its building has acquired the LEED platinum rating.
- Private ESCOs have mobilized and recently set up the Indian Council for Energy Efficiency Business (ICPEEB) to network, provide input to policy-makers, support business development, and disseminate information on energy efficiency.

USAID's Energy Conservation and Commercialization (ECO)

This program has a long history of association with BEE, starting with development of ECBC and continuing with the implementation under the third phase of the ECO program (ECO-III). BEE, USAID, and Asia-Pacific Partnership are actively collaborating under the ECO-III project to help with implementation of Energy Conservation Building Code (ECBC) (Kumar et al. 2010; USAID ECO-III project 2008c), through the following activities:

- Development of State Level Energy Conservation Action Plans;
- Assisting BEE in building the capacity of practising architects, building designers, energy auditors/consultants, State Designated Agencies and Municipalities to facilitate ECBC implementation;
- Promoting technical assistance to enhance energy efficiency in existing buildings and municipalities, and developing a framework of energy benchmarks for commercial buildings in India;
- Promoting energy efficiency in small and medium-sized enterprises (SMEs);
- Developing the Energy Efficiency Think Tank to enrich and facilitate energy efficiency policies and programs with active involvement of industry and other stakeholders;
- Promoting Demand side management (DSM) and Energy Conservation (EC) programs: Developing the Utility/Electricity Regulator driven DSM and EC Programs;
- Establishment of Regional Energy Efficiency Centers to promote energy efficiency in commercial buildings, domestic appliances, and industrial furnaces in SMEs;
- Building the capacity of architectural institutions and students in the field of Building Science and Energy Modeling, as a long-term strategy; and
- Promoting the transfer of energy efficiency experiences, knowledge and best practices between the US and India.

3. MEASURING ENERGY USE IN, AND CO_2 EMISSIONS FROM, EXISTING BUILDINGS IN THE UK, USA AND INDIA

A wide range of tools and checklists are available to measure energy use in buildings and improve their energy efficiency while also addressing wider sustainability issues. These can be used at various stages of building design, construction and operation to evaluate if targets are being met, or if they need to be reassessed or redefined.

3.1 Methodology and Outputs for Energy Measurement

Energy assessment tools can be classified based on two main approaches – predicted (simulated) data and actual (metered) energy consumption.

Energy prediction based on modeling is used to predict energy consumption or carbon emissions using energy models. *Models or simulation tools* vary in their scope and outputs but on the whole, allow designers to (USAID ECO-III project 2008b):

- Consider the building as a single integrated system;
- Predict thermal behavior of buildings in relation to their outdoor environment;
- Envisage the impact of daylight and artificial light inside the building;
- Model the impact of wind pattern and ventilation and assess their effect on energy use;
- Estimate the size/capacity of equipment required for thermal and visual comfort;
- Calculate the effect of various building components on one another and predict resulting conditions and their impact on energy use;
- Assess changes in energy consumption through sensitivity analysis with respect to design changes affecting building geometry, materials, components, systems, etc.

Energy prediction tools can be further subdivided into three categories: simulation models, correlation tools and scorecard rating tools (Gupta and Chandiwala 2007).

I. *Simulation models* are computer programs that are used to generate a performance prediction from calculations. A modeled scenario is simulated against pre-recorded data — typically relating to materials, equipment and climate in order to establish the likely performance and determine the efficiency of a design, for example, BREDEM for domestic buildings in the UK, EnergyPlus in the USA etc.

II. *Simplified energy models or correlation tools,* often referred to as performance-based tools, usually measure a particular element such as energy efficiency or thermal comfort and focus on providing a quick evaluation of a proposed design in the form of a simple indicator. These tools have often been derived from multiple results generated by simulation models, such as SAP for domestic buildings in the UK.

III. *Scorecard rating tools* provide an assessment where performance is measured through a point-scoring system. Points are achieved by meeting established criteria and the level of compliance determines the performance outcome. Scorecard programs are effectively checklists which focus on a holistic approach and outline intent and requirements. In addition, they also have the potential to incorporate possible design solutions by listing suggested methods to achieve the desired result. Various categories are often weighted depending on perceived importance and local requirements, and the total points are calculated to give a final rating eg. LEED, BREEAM, TERI-Griha.

Energy auditing is the second approach which involves collecting actual (metered) energy data for a representative sample of the building stock. Actual energy consumption data will generally be available in quite different forms from that which comes out of design models in general. For a building or premises, actual data is generally only known by fuel. End-uses (heating, cooling, appliances etc) will not be known unless they are specifically sub-metered (CLG and UKGBC 2007). Usually, measuring energy consumption of dwellings is much simpler than that of non-domestic buildings. There are no building services involved, occupancy patterns are similar from dwelling to dwelling, and homes come in broadly similar built forms. By contrast, non-domestic buildings come in all shapes and sizes, they have a range of building services — some of them are complex and require careful commissioning and management, and occupancy patterns are varied (All Party Urban Development Group 2007).

Both *energy prediction* and *actual energy measurement* approaches can lead to three types of outputs, namely: benchmarking, rating systems and energy labeling (Perez-Lombard et al. 2009), depending on the nature and purpose of the expected output.

Energy benchmarking refers to a comparison of an Energy Performance Index (EPI) for a range of building types and sizes. Commonly used EPI are energy use per unit area of the building. EPIs can also be based on energy use per occupant, or per bed space in case of dwellings (Perez-Lombard et al. 2009). The benchmarking process generally comprises energy auditing (although it can be combined with prediction tools sometimes) by measuring energy use in existing buildings to create a database of a significant number of buildings. The number of parameters that data is collected for varies widely from one country to another. Benchmarks are generally classified as typical and good practice values and adjusted for climate and sometimes occupancy-related variations so as to be applicable for comparison for a substantial number of buildings. Individual buildings can then be compared to these benchmarks to evaluate their relative energy performance. Benchmarks are an important tool for any country and generally the first step in energy management strategies, as they provide information about baseline typical energy use in different building types. Benchmarking is described in detail in the next section.

Energy rating systems may be defined as a "method for assessing energy quality" (Perez-Lombard et al. 2009). Unlike benchmarks, which compare the building performance to national or regional typical/good practice energy use, energy rating systems provide a definitive value of energy performance against a pre-defined target to provide a 'rating'. For existing buildings, rating systems generally are based on auditing of operational energy use. For new buildings, rating systems include initial predictive energy modeling for new buildings and may be followed by a process of measuring energy while in use. Energy ratings can be further classified into standard ratings for common building types within typical use and climate conditions or 'bespoke' ratings designed individually for a particular building to take into account its specific requirements.

Energy labeling was commonly applied initially to consumer electronic devices and lamps as a means to inform consumers about their choices and promote energy efficiency. This concept has been further extended to include buildings, to allow users to understand and compare energy use of building types by providing it a 'label'. Labeling systems generally employ a 'scale' of energy use, classifying energy use into performance bands or ranges which can be represented graphically. For ease of understanding, the scale may be a numeric measure such as 1-100 or is sometimes represented with letters of the alphabet. Mostly, the label is also accompanied by detailed energy use information such as energy use per unit area etc. There are sometimes overlaps in use within the energy rating and labeling systems, with some tools employing more than one method of measuring and representing energy use.

Based on the discussions above, the following sections describe the tools, approaches and methodologies for measuring building energy use in the UK, USA and India. Not all of these tools or measures are directly comparable for aims and/or the methodology deployed across each of the case study countries.

3.2 Comparison of Building Energy Use in the UK, USA and India

Table 2 shows the energy use indicators for domestic and non-domestic buildings. For domestic buildings, the energy use per unit area is higher in the UK than in the USA, while the energy per household is much higher in the USA as compared to UK. This is probably related to the difference in the average dwelling size which is 87m^2 in the UK and about 200m^2 in the USA. Hence, in spite of lesser energy per unit area, the USA uses more energy per household. Domestic energy use-related data was not available for India. For non-domestic buildings, the UK and USA both have a relatively similar energy use ranging from 262kWh/m2/yr to 287.2kWh/m2/yr respectively. For India, this figure derived from some recent energy audits is estimated to be around 189kWh/m^2/yr.

TABLE 2
Building-Related (Domestic and Non-Domestic) Energy Use in UK, USA and India

Criteria	National Benchmarking Databases		Individual Study Data
	BERR	**DOE**	**BEE, LBNL**
Domestic	**UK (2007)**	**USA (2005)**	**India**
Total number of households	26.142 million	111.10 million	232 million (73 million urban and 159 million rural)
Energy use per unit area	228 kWh/m2/yr	138 kWh/m2/yr	Data unavailable
Energy use per household	19,851 kWh/house/yr	27,815 kWh/house/yr	Electricity consumption per urban household will increase from 908kWh in 2000 to 2972kWh in 2020
Non-domestic*	**UK (2005)**	**USA (2003)**	**India**
Energy per unit area	262.1 kWh/m2/yr	287.2 kWh/m2/yr	189 kWh/m2/yr

*Figure for India is based on an average of recent audits of a representative sample of three types of commercial buildings; offices, hotels and hospitals.

3.3 Tools, Methodologies and Outputs for Building Energy Measurement in the UK

Many databases and tools exist in the UK for building energy measurement. For example, the recently established Department of Energy and Climate Change maintains a database of UK energy-related statistics including data for energy use in buildings, by sector and by end use. Table 3 presents some key tools for energy measurement, including BREDEM, SAP, SBEM, BREEAM, and the Code for Sustainable Homes.

TABLE 3
Key Approaches for Assessing Predicted and Actual Energy Use from Buildings in UK

Tools -UK	Description	Units	Type of Output
Energy Prediction: Simulation Tools			
BREDEM Building Research Establishment Domestic Energy Model	Estimates energy requirements in different dwelling types including running cost, calculating energy efficiency savings in up gradation of existing houses, and calculating an energy rating for a dwelling.	Annual fuel use, fuel costs and CO_2 emissions	Rating system
Energy Prediction: Simplified Energy Models Or Co-Relation Tools			
SAP Standard Assessment Procedure	National methodology for calculating the energy performance of dwellings for building regulations compliance for new and renovation of existing dwellings. Simplified model based on BREDEM	Energy cost rating (the SAP rating from 1-100), Environmental Impact rating based on CO_2 emissions (the EI rating)	Rating system
	Also used for Energy Performance Certification purposes i.e EPCs for new dwellings. (For existing dwellings, it is accompanied with an on-site evaluation by assessors)	Energy Efficiency Rating A-G Environmental Impact (CO_2) Rating A-G	Labelling system
SBEM Simplified Building Energy Model	National methodology for calculating the energy performance of dwellings for building regulations compliance for new and renovation of existing non-domestic buildings.	Monthly energy use and the building's carbon dioxide emissions rate (BER)	Rating system
	Also used for Energy Performance Certification purposes i.e EPCs for NEW non-domestic buildings. (For existing buildings, it is accompanied with an on-site evaluation by assessors)	Energy Efficiency Rating A-G Environmental Impact (CO_2) Rating A-G	Labelling system
Energy Prediction: Scorecard Rating Tools			
Code for Sustainable Homes (CSH) Building Research Establishment	Voluntary rating system for new dwellings based on performance in nine environmental categories. The code assigns one of the six predefined energy performance levels to a new dwelling	Rating of level 1 - 6, Level 6 being the most efficient zero carbon target	Rating system
BREEAM Building Research Establishment Environmental Assessment Method	Voluntary scheme for environmental rating of building designs of non-domestic buildings. Standard BREEAM types exist for common buildings such as schools, offices etc. Bespoke BREEAM for other buildings	Pass, good, very good and an excellent rating	Rating system
Actual Energy Measurement Tools			
Display Energy Certificates (DEC)	European Energy Performance Building Directive requires Display Energy Certificates required since October 2008. It is based on metered energy data for larger public buildings.	Energy Efficiency Rating A-G Environmental Impact (CO_2) Rating A-G	Labelling system

Apart from the mandatory tools and compliance rating standards, the UK is at the forefront of developing area-based methodologies for facilitating rapid and large-scale retrofitting of buildings, especially dwellings. In this regard, DECoRuM® —the Domestic Energy, Carbon-Counting and Carbon-Reduction Model — was developed as a GIS-based toolkit for carbon emissions reduction planning in cities, with the capability to estimate current energy-related CO_2 emissions from existing UK dwellings, aggregating them at street, district, sub-urban, and city levels. DECoRuM® can evaluate the potential and financial costs for domestic CO_2 emissions reductions by deploying a whole range of best practice energy efficiency measures, low carbon systems and renewable energy technologies. Successful application of the model has been completed in Oxford and parts of London (Gupta 2005a; 2005b; 2007; 2008). More information about the model and its methodological approach is available from www.decorum-model.org.uk.

3.4 Tools, Methodologies and Outputs for Building Energy Measurement in the USA

The Department of Energy (DOE) and Environmental Protection Agency (EPA) are key government departments for all building energy-related policies in the USA. DOE carries out a periodic national sample survey of commercial (Commercial Buildings Energy Consumption Survey, CBECS) and residential (Residential Energy Consumption Survey, RECS) buildings. This database is used to benchmark energy use indicators for different building types, and provides information on energy use, cost and other energy related building characteristics (discussed in detail in the next section).

For common commercial building types, the CBECS dataset is linked to the *Target Finder* worksheets to set energy targets and rate a building design's estimated energy use based on building type and climate. For existing commercial buildings, the *Portfolio Manager* tool allows online management of buildings' operational energy performance data and provides ratings based on comparison with the CBECS database. Table 4 presents some of the key tools for energy measurement, including Energy plus, Energy Star and LEED.

TABLE 4
Key Approaches for Assessing Predicted and Actual Energy Use from Buildings in the USA

Tools -USA	Description	Units	Type of Output
Energy Prediction: Simulation Tools			
Energy Plus	Whole building energy analysis including heating, cooling, lighting, ventilating, and other energy flows as well as water of building types based on different climatic zones	Energy performance	Rating system
Energy Prediction: Simplified Energy Models Or Co-Relation Tools			
Target finder/	Energy performance rating system for design projects and major building renovations of common commercial buildings based on building type and location. It is linked to the energy database of CBECS.	Energy use (btu/sq. ft) Water use	Rating system
Energy star (Residential buildings) Environment Protection Agency (EPA) and Department of Energy (DOE)	The energy performance of new and existing commercial facilities is compared to the CBECS database via the 'target finder' and 'portfolio manager'. Buildings achieving a score of 75 or higher are awarded the Energy Star, indicating that they are among the top 25% of facilities in the country for energy performance.	Energy star label Buildings rated on a scale of 1-100	Labelling system
Energy star (Residential buildings) Environment Protection Agency (EPA) and Department of Energy (DOE)	New dwellings which incorporate EPA guidelines for energy efficient details and specifications, qualify for 'Designed to Earn the Energy Star'. It is followed by an independent onsite inspection by 'Home Energy Rater', to verify that a dwelling is awarded the Energy Star.	Energy star label Buildings rated on a scale of 1-100	Labelling system
Energy Prediction: Scorecard Rating Tools			
LEED	LEED is a third-party voluntary certification program and the nationally accepted benchmark for the design, construction and operation of high performance green buildings.	4 Levels Certified, silver, gold, platinum	Rating system
Actual Energy Measurement Tools			
Portfolio manager	Interactive energy management tool that allows to track and assess energy and water consumption across an entire portfolio of buildings by setting targets, comparing performance to those in the national CBECS database, and rate buildings to receive an EPA recognition for superior performance.	Energy use (btu/sq. ft) Water use Linked to energy star rating.	Rating system

3.5 Tools, Methodologies and Outputs for Building Energy Measurement In India

Energy measurement in the building sector is at an emerging stage in India, compared to the USA and the UK. In order to accelerate energy efficiency activities in commercial buildings, BEE has developed a scheme for *star rating of buildings*, based on actual performance of the building, called the Energy Performance Index (EPI). EPI is expressed in terms of *kWh/sq.m/year,* and measured in terms of purchased & generated electricity divided by built up area in square meters. However the total electricity does not include electricity generated from on-site renewable sources such as solar photovoltaics, wind turbines etc.

3.6 Comparative Evaluation of Building Energy and Environmental Rating Systems

Commonly-used voluntary rating systems for green buildings in the domestic and the non-domestic sector in all three case study countries vary in their scope of evaluation, ranging from new builds and major renovations to evaluating buildings while in use for their operation and maintenance.

In the UK, voluntary rating systems have been primarily formulated and certified by the Building Research Establishment (BRE). The two main

TABLE 5
Comparison of Key Voluntary Rating Systems for Green Buildings in UK, USA and India

Voluntary Rating System	CSH – UK	BREEAM — UK	LEED for Homes —USA	LEED — Commercial Buildings USA	TERI GRIHA — India	LEED — India
New build/ refurbish-ment/ both	New build residential only (ECOHOMES – for existing dwellings)	New build/ refurbish-ments of non-do-mestic buildings BREEAM – In Use for occupied buildings.	New homes only (LEED exists for other building types)	New build/refur-bishments — Operations and maintenance for in use buildings.	New do-mestic and non-domestic buildings	New construction, Core and shell
Lead agency	Government, supported by BRE and others	BRE	US Green Build-ing Council	US Green Building Council	TERI— the Energy Resource Institute	Indian Green Building Council
Operational since	Operational since 2007, Manda-tory evaluation of new houses since may 2008	Operational for homes and offices since 1990. Have been revised and new building types added.	2007	Pilot in 1998, rating system since 2000.	Novem-ber 2007, launched later in some parts of India.	2007

TABLE 5, *continued*

Voluntary Rating System	CSH – UK	BREEAM — UK	LEED for Homes —USA	LEED — Commercial Buildings USA	TERI GRIHA — India	LEED — India
Stage assessment	Review at design stage Certification on build completion	Design stage assessment. Post construction review for new buildings in some categories. Operational energy use assessment for occupied buildings.	Preliminary rating at design stage Certification on build completion	Preliminary rating at design stage Certification on build completion	Three stage assessment by Preliminary, evaluation and advisory committees	Preliminary rating at design stage Certification on build completion
Rating levels	1-6 star scoring system 6 – zero carbon house	Pass. Good, very good, excellent or outstanding rating.	4 grades – certified, silver, gold, platinum	4 grades – certified, silver, gold, platinum	1-5 star	4 grades – certified, silver, gold, platinum
Parameters considered	1. Energy/CO_2 — 2. Water 3. (Minimum standards at each level) 4. Materials 5. Surface water run-off 6. Waste 7. Pollution 8. Health and well being 9. Management and Ecology	1. Management 2. Health and Wellbeing 3. Energy 4. Transport 5. Water 6. Material and Waste 7. Landuse and Ecology 8. Pollution	1. Location and linkages 2. Sustainable sites 3. Energy and atmosphere 4. Materials and resources 5. Water efficiency 6. Indoor environmental quality 7. Homeowner awareness	1. Sustainable sites 2. Water efficiency 3. Energy and atmosphere 4. Materials and resources 5. Indoor environmental quality	1. Site selection and site planning 2. Building planning and construction 3. Building operation and maintenance Areas covered — • Conservation and efficient utilisation of space • Health and well being • Water use, recycle and reuse • Energy – end use, embodied, renewable	1. Sustainable site development 2. Water savings 3. Energy efficiency 4. Materials selection 5. Indoor environmental quality 6. Innovation and design process
Self rated or rated by independent experts	Independent assessors	Independent assessors	Performance test and inspection by LEED for homes ‘providers’	Performance test and inspection by LEED assessors	Evaluation and advisory committee consisting of self and independent assessments	Performance test and inspection by LEED assessors
Well regarded or known standard	Aims to lead the way for building regulations revisions	Industry standard in the UK	Industry standard in the USA	Industry standard in the USA	First rating system developed in India.	Initial stages of application in India.

rating systems are BREEAM, BRE Environmental Assessment Method for non-domestic buildings, and the recently launched Code for Sustainable Homes (CSH) for new dwellings.

Leadership in Energy and Environmental Design (LEED), is a Green Building Rating System developed by the US Green Building Council. It is the nationally accepted benchmark for the design, construction and operation of high performance green buildings and follows a whole building approach to environmental designs.

India is the latest country to develop its own green building rating systems. Currently, two rating systems are available, both of which are in their nascent stage of application:

- GRIHA — Green Rating for Integrated Habitat Assessment has been developed by the Energy Research Institute. It can be used to assess offices, retail spaces, institutional buildings, hotels, hospital buildings, healthcare facilities, residences, and multi-family high-rise buildings, and was first launched in parts of the country in 2007. It is closely linked to the requirements of the new Energy Conservation Building Code in India which is soon expected to become a mandatory regulation for large commercial buildings.
- The second rating system, LEED-India has been developed by the Indian Green Building Council. It has been adopted from the LEED-USA standard and revised to suit Indian requirements. The LEED-India has been adopted and modified from the US-LEED rating system by the IGBC and the Confederation of Indian Industries. Like the US rating system, it is a voluntary standard in India and awards four rating types of Certified, Silver, Gold and Platinum based on an assessment of six environmental categories.

Table 5 compares some essential information about all the above mentioned rating tools.

4. ENERGY/CO_2 STANDARDS AND BENCHMARKS FOR EXISTING BUILDINGS

Several organizations (governments, NGOs, trade organizations) are developing energy and CO_2 standards and benchmarks for existing buildings in the UK, US and India, which are summarized in Table 6 (as shown below).

TABLE 6
List of Organisations Involved in Developing Energy/CO_2 Standards for Existing Buildings in UK, USA and India

Organisations Developing Energy/CO_2 Standards for Existing Buildings in UK, USA and India		
UK	**USA**	**India**
Building regulations Part L — CO_2 emissions requirements for new (or extensions to existing) buildings	Department of Energy, Energy Information Administration, and EPA's Energy Star Benchmarking programs	BEE's Star Rating EPI benchmarking program
Chartered Institution of Building Services Engineers (CIBSE) - provides benchmarks for both Energy use and CO2 emissions for 29 categories of buildings.	Residential Energy Consumption Survey (RECS)	Green Rating for Integrated Habitat Assessment (GRIHA)
Home Energy Efficiency Database (HEED)	Commercial Buildings Energy Consumption Survey (CBECS)	USAID ECOIII project to audit and benchmark energy use in commercial buildings
Passiv Haus Institute – commonly used European energy standard called Passiv Haus	Architecture 2030 net zero energy buildings (a common goal endorsed by AIA, ASHRAE, IESNA, USGBC, DOE, and Target Finder)	Indian Green Building Council — LEED India
Association of Environment Conscious Builders (AECB)	National Association of Home Builders (NAHB)-National Green Building Standard	
Energy Saving Trust (EST)	American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE) — energy standard for labelling commercial buildings	

Table 7 compares the operational energy use benchmarks for a range of building types in the UK, USA and India. The US energy benchmarks have been converted into kWh/m^2 for ease of comparison between different building types. Typical figures for buildings are given below. For India, energy (electricity use) benchmark figures have recently become available for three building types only, although work is ongoing to establish benchmarks for other building types (Kumar et al. 2010).

TABLE 7
Benchmarks for Common Building Types in UK, USA and India

	USA Average Site EUI (EIA)		**UK Benchmarks (CIBSE TM 46)**		**India (USAID-ECO III)**
Building use description	Electricity (kWh/m2/yr)	Fossil fuel (kWh/m2/yr)	Electricity (kWh/m2/yr)	Fossil fuel (kWh/m2/yr)	Electricity (kWh/m2/yr)
Education	151	89	-	-	-
School	*	*	40	150	-
College/university	239	140	80	240	-
Food sales	610	99	-	-	-
Grocery store/ food market	*	*	400	105	-
Convenience store	684	76	310	0	-
Food service	653	454	-	-	-
Restaurant/cafeteria	505	448	90	370	-
Fast food	1078	607	-	-	-
Health care: inpatient	337	380	-	-	-
Hospital	*	*	90	420	Multi-speciality hospitals: 378 Government hospitals: 88
Health care: long term care	211	180	65	420	-
Health care outpatient	166	64	-	-	-
Clinic	201	64	70	200	-
Lodging	167	107	-	-	-
Dormitory	*	*	60	300	-
Hotel, motel, inn	*	*	105	330	279
Mall	240	98	-	-	-

TABLE 7, *continued*

	USA Average Site EUI (EIA)		UK Benchmarks (CIBSE TM 46)		India (USAID-ECO III)
Office	*	*	95	120	180
Bank/financial institution	*	*	140	0	One shift buildings: 149 Three shift buildings: 349 Public sector buildings: 115 Private sector buildings: 258
Public assembly	119	90	-	-	-
Entertainment/ culture	189	111	150	420	-
Library	194	135	70	200	-
Recreation	113	92	150	420	-
Social meeting	94	71	70	200	-
Public order and safety	162	122	-	-	-
Fire/police station	138	108	70	390	-
Service (vehicle repair, service, postal service)	153	90	35	180	
Storage/ shipping/ non-refrigerated warehouse	44	35	35	160	-
Refrigerated warehouse	*	*	145	80	-
Religious worship	75	70	20	105	-
Retail (non-mall stores, vehicle dealerships)	173	85	165	0	-
Others	184	144	-	-	-

*For USA, these benchmarks can be found via the ‘target finder’.

5. POTENTIAL FOR REDUCING CO_2 EMISSIONS FROM EXISTING BUILDINGS: REVIEW OF STRATEGIES IN UK, USA AND INDIA

5.1 Overview of Strategies for Reducing CO_2 Emissions from Buildings

Based on a range of literature reviewed (All Party Urban Development Group 2007; ASHRAE, 2008; Boardman 2007a, 2007b; CL, 2006; Creyts et al. 2007; EPA 2003; Lowe 2007; Majumda 2000; Mazria and Kershne 2008; Parke 2009; Pout and MacKenzie 2005; Urge-Vorsatz et al. 2007a, 2007b; USAID ECO-III project 2008d), the key principles for reducing energy use and CO_2 emissions from existing buildings include:

- Reducing the demand for energy (heating, cooling, lighting or ventilation) through a range of end-use energy efficiency measures, which address different end uses of energy in buildings as discussed in sections 2.1, 2.2 and 2.3;
- Providing the reduced demand through low carbon and/or zero carbon technologies;
- Decarbonizing the electricity supply. For instance, Lowe (2007) concludes that an increase in the rate of decarbonization from the UK historical figure of just over 1.5% per annum to just over 2% would be sufficient to reduce the carbon intensity of UK electricity from its current value of around 0.55 $kgCO_2/kWh$ to 0.2 $kgCO_2/kWh$ by 2050;
- Providing feedback on actual energy used in buildings through smart metering to empower building occupants to control and manage their energy use; and
- Undertaking regular post-occupancy evaluation studies of completed refurbished projects to provide evidence-based lessons for the building community and users.

To apply these principles of CO_2 reduction, a whole building approach should be deployed, by installing as many energy efficiency improvement measures as possible and appropriate within a single home. Such an approach is being promoted in the UK currently through government consultation (DECC 2009b). Models such as DECoRuM, discussed above, can help in measuring, modeling, mapping and reducing domestic CO_2 emissions (Gupta 2005a, 2007).

Over the years, research on post-occupancy evaluation of buildings have shown that there is a wide credibility gap between designed energy use versus actual energy consumption, due to (Bordass and Leaman 2005; Gupta 2005c; Way and Bordass 2005):

- Little monitored information and feedback being available on building performance in use to those who procure and regulate buildings.
- Problems with design, specification, build quality, commissioning, handover, operation, controls, usability, management and communication.
- More equipment, using more electricity in particular and often requiring yet more equipment to cope with the consequences.
- Unmanageable complications as we throw more and more technologies into buildings, when what we really need is to keep it simple and do it well.

A number of monitoring studies and modelling approaches have calculated the savings associated by several measures taken singly, or in combination. For example, in a carefully documented retrofit of four representative houses in the York region of the UK, installation of new window and door wood frames, sealing of suspended timber ground floors, and repair of defects in plaster reduced the rate of air leakage by a factor of 2.5-3.0 (Bell and Lowe 2000). This combined with improved insulation, doors, and windows, reduced the heating energy required by an average of 35%. Bell and Lowe believe that a reduction of 50% could be achieved at modest cost using well-proven (early 1980s) technologies, and a further 30-40% reduction through additional measures. Similarly, there are numerous published studies, summarized by Harvey (2006), showing that energy savings of 50-75% can be achieved in US commercial buildings through aggressive implementation of integrated sets of retrofit measures. In the early 1990s, a utility in California sponsored a US$10 million demonstration of advanced retrofits, whereby six retrofit projects achieved an energy savings of 50%, while in the seventh project, 45% energy savings was achieved.

Standard retrofit measures such as thermal envelope upgrades can be combined with more radical measures that involve reconfiguring the building so that it can make direct use of solar energy for heating, cooling, and ventilation. Task 20 of the IEA's Solar Heating and Cooling (SHC) implementing agreement was devoted to solar retrofitting techniques. Solar renovation measures that have been used are installation of roof- or facade-integrated solar air collectors; roof-mounted or integrated solar hot water heating; transpired solar air collectors; advanced glazing of balconies; external transparent insulation; and construction of a second-skin facade over the original facade. Energy savings of 40-70% have been achieved in this way, as documented by Boonstra and Thijssen (1997) and Voss (2000).

Despite these monitoring studies of retrofits, there has been a general lack of literature that quantifies the global potential for energy-efficiency improvements in the world's buildings. To fill this gap, an analysis was conducted in the context of this study based on national and regional studies, which are more abundant (Urge-Vorsatz et al. 2007a, 2007b). Table 8 provides a summary of the estimates of different types of CO_2 mitigation potential in different world regions and countries and it ranks the most promising options in terms of the size of potential and its mitigation cost.

TABLE 8
CO_2 Emissions Reduction Potential for the Building Stock in 2020

Economic Region	Countries/Country Groups Reviewed for Region	Potential as a Percentage of the National Baseline for Buildings	Measures Covering the Largest Potential	Measures Providing the Cheapest Mitigation Options
Developed Countries	US, EU-15, Canada, Greece, New Zealand, Australia, Republic of Korea, UK, Japan, Germany	Technical: 21-45% Economic: 12-25% Market: 15-37%	1. Shell retrofit including insulation especially windows and walls 2. Space heating systems and standards for them 3. Efficient lights, especially shift to CFLs and efficient ballasts	1. Appliances such as efficient televisions and peripheries (both on-mode and standby), refrigerators and freezers followed by ventilators and air-conditioners 2. Water heating equipment 3. Lighting best practices
Economies in Transition	Hungary, Russia, Poland, as a group: Latvia - Lithuania - Estonia, Slovakia, Slovenia, Hungary, Malta, Cyprus, Poland, Czech Republic	Technical: 26 - 47% Economic: 13 - 37% Market: 14%	1. Pre- and post- insulation and replacement of building components, especially windows 2. Efficient lighting, especially shift to CFLs 3. Efficient appliances such as refrigerators and water heaters	1. Efficient lighting and its controls 2. Water and space heating control systems 3. Retrofit and replacement of building components, especially windows
Developing Countries	India, Indonesia, Argentina, Brazil, China, Ecuador, Thailand, Pakistan, Middle East as a group	Technical: 18-41% Economic: 13-52% Market: 23%	1. Efficient lights especially shift to CFLs, light retrofit and kerosene lamps 2. Various types of improved cook stoves, especially biomass stoves, followed by LPG and kerosene stoves 3. Efficient appliances such as air-conditioners and refrigerators	1. Improved lights, especially shift to CFLs light retrofit, and efficient kerosene lamps 2. Various types of improved cook stoves, especially biomass based, followed by kerosene stoves 3. Efficient electric appliances such as refrigerators and air-conditioners

Source: Urge-Vorsatz et al. 2007a.

According to Table 8, efficient lighting technologies are among the most promising measures in buildings, in terms of both cost-effectiveness and size of potential savings in almost all countries. In developing countries, efficient cooking stoves rank second, while the second place measures differ in the industrialized countries by climatic and geographic region. Almost all studies examining economies in transition (EiT, which have typically cooler climates) have found heating-related measures to be most cost-effective, including insulation of walls, roofs, windows and floors, as well as improved heating controls for district heat. In developed countries, appliance-related measures are typically identified as the most cost-effective, with cooling-related equipment upgrades ranking high in the warmer climates. Other measures that rank high in terms of savings potential are solar water heating, efficient lighting, and efficient appliances, as well as building energy management systems.

In addition to physical intervention, it is important to provide feedback on energy use in buildings improved for CO_2 reduction to enable occupants to be part of the solution. Every low carbon refurbished building should have an electricity and gas monitor to help building occupants understand exactly how much energy they are using and CO_2 they are producing. Smart meters are one technology, which allow energy suppliers to communicate directly with their customers, removing the need for meter readings and ensuring entirely accurate bills with no estimates. Consumption information can be provided to domestic customers through an integrated, in-home display. Among other potential benefits, they could offer gas and electricity customers accurate bills and provide information that could help them use less energy and encourage energy efficiency (DECC 2009c).

Clearly, a successful strategy for improving the carbon performance of the existing building stock in the developed and developing worlds will depend on the participation of occupants/building owners, the source of funding (ideally coupled with tax incentives) and the most effective technical solution. On completion of a project to reduce CO_2 emissions, extensive feedback consultation ensures that the project aims have been met and that lessons are learnt for future projects.

5.2 Potential for Reducing CO_2 Emissions from Buildings in the UK

5.2.1 Domestic Building Sector

In the UK, a range of studies over the last five years has established the feasibility of reductions in excess of 60% or 80% by 2050 based on detailed technical scenarios and models (Johnston 2003; Johnston et al. 2005). Most of the studies conclude that CO_2 emissions from UK housing may initially be reduced through improving the thermal efficiency of the building fabric and improving the efficiency and controls of boilers and heating. Further savings may be made through installing efficient appliances, improving control of energy use, and reducing the carbon content of energy sources by installing micro-generation technologies.

Bottom-up studies using the DECoRuM model on a local scale in Oxford, covering 318 dwellings, indicate that technically CO_2 emission reductions above 60% from the case study dwellings are possible, at a cost of between £6 to £77 per tonne of CO_2 emissions saved, depending upon the package of measures used, and the scenario of capital costs (low or high) employed (Gupta 2007). Extrapolation of CO_2 emission savings from the case study dwellings to the UK housing stock, taking into account the different proportions of dwelling built forms in the case study and UK housing stock, shows an overall potential for saving about 92MtCO_2 or 25MtC per year, at a capital cost of £150 billion to £234 billion. This is equivalent to a reduction of 66% of UK housing stock CO_2 emissions in 2000 (Gupta 2007).

On a UK housing stock level, studies by the UK Government have estimated the capital costs, CO_2 savings, and payback period of a whole range of domestic CO_2 reduction measures (CLG 2006). The measures in Table 9 are ranked in order of their cost effectiveness. This is measured by the length of financial payback — how many years it takes for the benefits in terms of energy bill savings to equal the cost of installation. Cost effectiveness here is related purely to the energy efficiency element of the measure. Cavity wall insulation currently offers the largest potential carbon saving per dwelling and across the whole stock within a 3-year payback period. Other cost effective measures generally offer lower carbon savings. Other measures, such as micro Combined Heat and Power (CHP), solid wall insulation and ground source heat pumps, have the potential to achieve relatively large potential carbon savings. However, a high up-front installation cost means that these have longer payback periods and, therefore, are not particularly cost-effective for households without additional support or incentives.

TABLE 9
Typical Measures for Reducing CO_2 Emissions from UK Domestic Stock (Potential savings are based on a typical 3-bed semi-detached property)

Measures	Average Cost (£)	Cost Saved (£.yr)	Carbon Saved (kgC/yr)	Payback (yrs)	Potential Total Carbon Saving (MtC/yr)
Building fabric improvements					**10.6**
Cavity wall insulation	342	133	242	2.6	2.1
Loft insulation (full and top-up)	284	104	190	2.7	1.2
Draught proofing	100	23	43	4.3	0.4
Solid wall insulation	3150	380	694	7.5	5.2
Windows (single to double glazing)	4000	41	26	97.6	1.7
Improving heating system efficiency and related controls					**3.3**
Hot water cylinder insulation	14	29	53	0.5	0.1
Improved heating controls	147	43	77	3.4	0.2
A rated boiler	1500	168	177	8.9	3.0
Micro generation					**27.1**
Micro CHP	1571	230	508	6.8	6.1
Micro wind	2363	224	263	10.5	-
Ground Source Heat Pump	4725	368	990	12.8	16.8
Photovoltaic electricity	9844	212	249	46.4	2.5
Solar water heating	2625	48	88	54.7	1.7

Source: CLG 2006.

5.2.1 Non-Domestic Building Sector

Studies by BRE (Pout 2000; Pout and MacKenzie 2005) consider a wide range of energy efficiency measures, and for each one assess the potential carbon savings and their cost-effectiveness based on discounted cash flow calculations to provide an indication of where the greatest carbon savings are likely to be realised. The results indicate potential carbon savings around 20% of the total non-domestic (commercial and public sector) carbon emissions can be achieved cost-effectively, typically with lighting and heating upgrades.

Additional carbon savings could be made with greater use of alternative renewable and low carbon technologies such as PV and heat pumps. At current prices, these measures are very rarely cost-effective.

A second study identified some key barriers related to the availability of information on energy consumption, the economic costs of retrofitting and coordination between owners and occupiers, and physical constraints that dictate what is feasible in terms of retrofitting buildings to make them more energy efficient (All Party Urban Development Group 2007). Building regulations only started to set energy efficiency standards in 1985, and an estimated 40% of buildings were built before this date. In addition, certain buildings may not be suitable for specific types of improvements, e.g. historic buildings, urban buildings that lack solar access, sufficient roof, etc. (English Heritage 2004). In particular, existing stock cannot be retrofitted to comply with 'new build' standards. Therefore, different types of non-domestic buildings may require different benchmarks – albeit along a standard scale. An approach that rewards relative, rather than absolute, improvements may be the way forward. Simply rewarding the highest performer may have unintended consequences if most existing buildings cannot achieve the desired standard.

5.3 Potential for Reducing CO_2 Emissions from Buildings in the USA

Recently, McKinsey & Company led a study to comprehensively understand the cost of various options for reducing the greenhouse gas (CO_2) emissions within the United States including the building sector. The primary goal of the U.S. Greenhouse Gas Abatement Mapping Initiative (US GHG AMI) is to create a consistent, detailed fact base to support policy design and inform economically sensible strategies on the issue of climate change.

Emissions associated with buildings and appliances are projected to grow faster than those from any other sector. Emissions from commercial buildings and their equipment and appliances are expected to grow 1.8% annually, with those from residential buildings and appliances growing 1.5% (Creyts et al. 2007). While the commercial building stock is forecast to increase by 48 percent by 2030 (rising from 73 billion to 108 billion square feet), between 2005 and 2030, the U.S. would see a net increase of 34 million new homes, with the average size of all homes rising by 14% to approximately 2,000 square feet. This would be the equivalent of adding a room 16 feet long by 15 feet wide to every household. Despite the increase in the numbers and size, the carbon intensity of U.S. residential buildings will remain flat through 2030, at nearly 11 tons per household per year.

Residential Buildings: The nation's housing stock is forecast to grow from 113 million homes to 147 million by 2030, with most of these houses built to a minimum performance standard below desirable economic and efficiency levels. As a consequence, any new-build home in the nation — regardless of region — represents an opportunity to create long-lasting abatement at negative cost. In addition, roughly 20 million existing homes (by 2030) would be candidates for retrofit improvements to the building shell, particularly in areas where heating prevails and the building stock is older. In such regions as the Northeast, East North Central and West North Central census divisions, increased attic insulation would offer the biggest opportunity and could improve heating performance by nearly 30% from the reference case. Although retrofit improvements typically deliver substantial abatement, they cost much more than measures delivering similar impact on new-build construction.

Commercial Buildings: Similar growth is expected in commercial buildings. By 2030, total square footage of commercial buildings is forecast to increase from 73 billion to 108 billion, where more than 56 billion square feet of this commercial space will have been built new or rebuilt on-site. Although modifications in commercial building shells will improve heating and cooling efficiency by some 5-7%, there is significant additional abatement potential. Use of programmable thermostats and energy management systems — reducing thermal shorts, installing reflective roof coating, improving tightness, and using advanced insulation types — may improve heating and cooling efficiency by an additional 15-20%.

5.4 Potential for Reducing CO_2 Emissions from Buildings in India

The Energy Conservation Building Code (ECBC) was launched by the Bureau of Energy Efficiency (BEE) in 2007, for commercial buildings with peak demand in excess of 500kW or connected load in excess of 600kVA. In commercial and office buildings, energy is consumed by a range of appliances including lighting, HVAC systems, computers, copiers, and water coolers. The ECBC therefore encourages energy-efficient building systems, such as building envelope; lighting; HVAC (heating, ventilation and air conditioning); water heating; and electric power distribution, within the building facilities while enhancing thermal and visual comfort, and productivity of the occupants. Analysis undertaken during the development of the ECBC shows that energy savings in the range of 27-40% are possible for an ECBC-compliant building, in comparison to a typical commercial building with an annual energy consumption of 200kWh/m^2/year (Bureau of Energy Efficiency 2006b).

The Bureau of Indian Standards (BIS) has developed the National Building Code (NBC) as a guiding code to be followed by municipalities and development authorities in the formulation and adoption of building by-laws. In the latest edition (2005) of the NBC, some aspects of energy efficiency have been addressed through appropriate design, usage and practices with regard to building materials, construction technologies, and building and plumbing services, such as:

- Use of pozzolanas (such as fly-ash, rice husk ash, metakaoline, silica fume, ground granulated blast furnace slag, etc.) in concrete production;
- Daylight integration (indoor lighting levels to be met via day lighting);
- Artificial lighting requirements (levels) for indoor spaces;
- Ventilation standards (natural and mechanical) for optimal human health and well-being;
- Electrical standards (minimum power factor, allowances for diversity, etc.); and
- Selected HVAC design norms.

However, about 25-30% of electrical energy in India is consumed by the domestic building sector, by lighting, refrigerators, ceiling fans, washing machines and air conditioners. Therefore in 2006, BEE launched the *National Energy Labelling* scheme on a voluntary basis for refrigerators and tubular fluorescent lighting. Labeled products (refrigerators, air conditioners, motors and other appliances) have been in the market since 2006 (Bureau of Energy Efficiency 2006a). Each appliance is ranked on a scale of five stars, with more stars indicating higher efficiency and more power savings — thus the program motto of *More Stars, More Savings!* The labels provide information about the energy consumption of an appliance, and thus enable consumers to make informed decisions. Almost all fluorescent tubelights sold in India, and about two-thirds of the refrigerators and air conditioners, are now covered by the labeling program. The impact of *National Energy Labelling* is summarized in Table 10 below.

TABLE 10
CO_2 Impact of Energy Labelling

Appliance	CO_2 Reduction as an impact of Star labeling
AC	0.106476 Million Tons
Refrigerator	0.946334 Million Tons
Tubular Fluorescent Lamps	0.146880 Million Tons
TOTAL	1.1996690 Million Tons

Source: Kumar 2009.

To widen the scope for energy savings, BEE has also included several widely-used equipments and appliances such as distribution transformers, motors, color TVs, ceiling fans, geysers, LPG stoves and agricultural pumps under the 'Standards and Labeling' program in 2008-09.

On June 30, 2008, the Prime Minister's Council on Climate Change released India's National Action Plan on Climate Change (NAPCC). The NAPCC, along with its eight missions, serves as the first country-wide framework on climate change with the approval and support of the Government of India. The National Mission on Sustainable Habitat comprises three components, namely:

- Promoting energy efficiency in the residential and commercial sector;
- Management of municipal solid wastes; and
- Promotion of urban public transport.

In an attempt to promote energy efficiency in the residential and commercial sectors, the mission emphasises the extension of the Energy Conservation Building Code (ECBC), use of energy-efficient appliances, and creation of mechanisms that would help finance demand-side management.

5.5 Barriers to the Implementation of CO_2 Reduction Strategies and Measures

The previous sections have shown the significant potential for CO_2 mitigation in buildings through energy-efficiency measures, low/zero carbon technologies and non-technical solutions in the UK, USA and India. Implementing CO_2 mitigation options in buildings is associated with a wide range of ancillary benefits. These include the creation of jobs and business opportunities, increased economic competitiveness and energy security, social welfare benefits for low-income households, increased access to energy services, improved indoor and outdoor air quality, as well as increased comfort, health and quality of life.

There are, however, substantial barriers that need to be overcome to achieve these reductions in emissions. Certain characteristics of markets, technologies, and end-users can inhibit rational, energy-saving choices in building design, construction, and operation, as well as in the purchase and use of appliances. Based on an extensive literature review, the most important barriers that pertain to buildings are discussed (Boardman 2007b; Creyts et al. 2007; Planning Commission 2005; Urge-Vorsatz et al. 2007a). Barriers can range from *financial hurdles* such as higher initial costs usually required for energy-efficient products; *hidden costs and benefits* of energy-efficient technologies which are not captured directly in financial flows, and hence do not present a true scenario to the consumer; *market failures* which might arise due to policies or incentives not translating into actual benefits; and *behavioral constraints* of people or organizations that hinder energy efficient practices due to lack of incentives to change behavior or lifestyle choices (Urge-Vorsatz, D., S Koeppel et al. 2007). The Carbon Trust in the UK classifies these barriers into four main categories: real market failures; financial costs/benefits; behavioral/organizational; and hidden costs/benefits (The Carbon Trust 2005). Key barriers are summarized in Table 11 below.

TABLE 11
Types of Implementation Barriers

Barriers	Description
Financial	Upfront costs of products
Hidden Costs	Time costs; 'transaction costs' with providers; quality of product/cost differences; Information about suppliers
Lack of Information	Household knowledge on their level of energy expenditure and regarding how much, and at what cost (investment), energy can be reduced.
Risks and Uncertainty	Unsure of savings due to uncertainty on future energy prices
Poorly Aligned Incentives	In rental market, tenants have no incentive to reduce their energy use as their landlord covers the energy bill
Physchological/ Sociological	Habit and late adopter mentality
Regulatory	Some regulations cause difficulties for households to benefit from or consider energy efficient measures.

For developing countries such as India, there may be additional barriers, including measurement of baseline energy, knowledge gaps, enforcement, implementation evaluation/monitoring programs, building and urban planning by-laws, lack of mandatory requirement for minimum energy performance, and lack of competitive pricing and financial incentives.

Table 12 summarizes the range of policy instruments to overcome major barriers to implementation. Policy instruments are discussed in greater detail in the following section.

TABLE 12
Barriers to Energy Efficiency and Policy Instruments as Remedies

Barrier Category	Instrument Category	Policy Instruments as Remedies
Economic Barriers	Regulatory- normative/ regulatory informative Economic Instruments Fiscal Instruments	Appliance standards, building codes, energy efficiency obligations, mandatory labelling, procurement regulation, DSM programs EPC/ESCOs, Cooperative Procurement, Energy Efficiency Certificates Taxation, public benefit charges, tax exemptions, subsidies/ rebates/grants
Hidden Costs/ Benefits	Regulatory-normative Economic instruments Support action	Appliance standards, building codes EPC/ESCOs Public leadership programs
Market Failures	Regulatory-normative/ regulatory informative Economic instruments Fiscal instruments Support, information, voluntary action	Appliance standards, building codes, energy efficiency obligations, mandatory labelling, procurement regulation, DSM programs EPC/ESCOs, cooperative procurement, energy efficiency certificates, Kyoto flexibility mechanisms Taxation, public benefit charges, tax exemptions, subsidies/ rebates/grants Voluntary labelling, voluntary agreement, public leadership programs, awareness raising, detailed billing
Cultural/ Behavioural Barriers	Support, information, voluntary action	Voluntary labelling, voluntary agreement, public leadership programs, awareness raising, detailed billing
Information Barriers	Support, information, voluntary action Regulatory/informative	Voluntary labelling, voluntary agreement, public leadership programs, awareness raising, detailed billing, mandatory labelling, procurement regulations, DSM programs, mandatory audits
Structural/Political		Public leadership programs

Source: Kumar 2009 Creyts et al., 2007; The Carbon Trust 2005; Urge-Vorsatz et al., 2007a.

6. MANAGING ENERGY USE AND CO_2 EMISSIONS IN BUILDINGS

Previous research by Urge-Vorsatz, Koeppel, et al. (2007b) broadly categorizes all policies into four broad policy instruments: *control and regulatory instruments*, *economic and market-based instruments*, *financial instruments* and *information and voluntary instruments*. Within this context, an extensive literature review was undertaken to compare and evaluate key policies for the three case study countries.

6.1 Control and Regulatory Instruments

Control and regulatory policies which directly influence the environmental performance by regulating processes and products have been found to be one of the most effective policy instrument categories. Building codes are generally the foremost control instruments used by countries for increasing energy efficiency of the new building stock as well as major refurbishment projects. To remain effective, they should be constantly monitored, evaluated and revised in accordance with technological developments and market trends (Urge-Vorsatz et al. 2007b). Table 13 compares the commonly used control instruments for the UK, USA and India, which include: building codes, labeling programs, appliance standards, energy efficiency obligations and quotas, and mandatory demand-side management. Details about each of these can be found in these references: CLG 2007; Cyrill Sweet 2007; USAID and LBNL 2006; ASHRAE, India's Bureau of Energy Efficiency ECBC Codes 2007; EU EPBD; California AB 1132, DECC 2009a; and Foresight 2008.

TABLE 13
Control and regulatory instruments: UK, USA and India

Control and Regulatory Instruments			
Policy	**UK**	**USA**	**India**
Building codes	Part L - Conservation of Fuel and Power; Code for Sustainable Homes (CSH has 1-6 levels of sustainability with level 6 being the zero carbon target).	Model energy codes (MEC); Building Efficiency Standards and Codes, ASHRAE, xxx	Energy Conservation Act 2001 Energy Conservation building codes (ECBC)
Mandatory labelling program/	Energy performance of buildings directive (EPBD) ; Energy Performance Certificates and Display Energy Certificates		
	For appliances and equipment: EU Energy Labelling Directive	Federal Trade Commission's Appliance Labelling Rule	
Appliance standards	Market transformation programme, Energy Saving Recommended, Energy Star	Energy Star labelling of products	National energy labelling programme for appliances
	US/EC Agreement on co-ordinated energy labelling of office equipment		
Energy efficiency obligations and quotas	Renewable Obligation Certificate (ROC) to encourage renewable electricity generation Carbon Emissions Reduction Target (CERT) — utility companies to invest in reducing emissions from homes.		
Mandatory demand-side management (DSM)/	Warm Front, Decent Homes for low income houses		*Bachat Lamp Yojna* (Lamp Savings Project) — Provide CFL's at a reduced price

All of the instruments reviewed can achieve significant energy and CO_2 emissions savings; however, the costs per ton of CO_2-equivalent saved vary greatly. Based on a study of over 60 ex-post policy evaluation reports from about 30 countries (Koeppel and Ürge-Vorsatz 2007), it was found that *control and regulatory mechanisms* are generally effective if enforced, and the cost-effectiveness is dependent on the enforcement costs. Building codes and appliance standards were found to achieve the highest CO_2 emissions reductions while appliance standards and energy-efficiency obligations were found to be among the most cost-effective policy tools. Regulatory instruments need to be supported by sound financial incentives to encourage users to take up energy efficiency as well as economic instruments to drive innovation in the industry. Also, information-based policies are key to generating awareness, whilst wide-scale acceptance leads towards positive behavior change.

6.2 Economic and Market-Based Instruments

Various economic, market-based, and fiscal mechanisms often are promoted by regulatory incentives. The most commonly-used policy is energy performance contracting whereby an Energy Service Company (ESCO) guarantees certain energy savings for a location over a specified period, implements the energy efficiency improvements, and is paid from the actual energy cost reductions achieved through the savings. ESCOs have been shown to be successful in achieving energy savings, because they make a life-cycle cost approach to energy use easier to apply in practice, and offer the opportunity for shared savings by aggregating users. A summary of economic and market-based instruments for UK, US, and India is given in Table 14.

In India, six government buildings used ESCOs to carry out retrofits through performance contracting in an attempt to promote and involve ESCOs. The BEE is also working on developing model contracts, accreditation, ratings, and financing to encourage energy service companies. Private ESCOs have also mobilized and recently set up the Indian Council for Energy Efficiency Business (ICPEEB) to network, provide input to policy-makers, support business development, and disseminate information on energy efficiency.

Except for energy performance contracting, most economic or market-based instruments such as cooperative procurement, energy efficiency certificate schemes and Kyoto Protocol flexible mechanisms are relatively new in the buildings sector and have just been applied for a few years in selected countries (Urge-Vorsatz et al. 2007b). Energy efficiency certificate schemes are still in development stages. A key initiative by the EU called the European Union Emissions Trading System (EU ETS) specifies a limit or ‘cap’ on emissions from the power sector as part of the EU Climate Policy. The USA is currently

TABLE 14
Economic and Market-Based Instruments: UK, USA and India

Economic and market-based instruments			
Policy	**UK**	**USA**	**India**
Energy performance contracting	ESCO reasonably advanced in the UK	Energy Savings Performance Contracts formalised as part of the Federal energy management programme	Six government buildings used ESCOs to carry out retrofits through performance contracting
Energy efficiency certificate schemes	European Union Emissions Trading System (EU ETS) limit or 'cap' on emissions from the power sector	The Western Climate Initiative; cap and trade program for United States and Canada – in the pipeline	
Kyoto Protocol flexible mechanisms			Clean Development Mechanism projects - allowing industrialised countries to invest in emission reduction projects in developing countries as an alternative

planning to lay the foundation for an international cap and trade program that would involve both the United States and Canada, called the Western Climate Initiative (WCI).

6.3 Financial Instruments

Financial instruments include taxation measures, fiscal grant programs, weatherization assistance programs, and others. Some examples of these instruments are summarized for the UK, US, and India in Table 15.

TABLE 15
Financial Instruments: UK, USA and India

Financial Instruments			
Policy	**UK**	**USA**	**India**
Taxation (on CO_2 or house-hold fuels)	Climate Change Levy on the use of energy in industry, commerce and the public sector		
Tax exemptions/ reductions	Enhanced Capital Allowances for energy saving technologies Reduced VAT on energy saving materials and micro generation technologies		
Capital subsidies grants, loans	*Warm Front:* to tackle fuel poverty Landlord's Energy Saving Allowance (LESA)	Weatherization Assistance Program 21 — cost-effective energy efficiency improvements for low-income households.	*Rajiv Gandhi Gramin Vidyutikaran Yojna* States to distribute free CFLs to below poverty line families.

6.4 Information and Voluntary Instruments

Information-based programs can lead to large savings at low costs in buildings, while information programs can also achieve significant savings and effectively accompany other policy measures. All three case study countries have a wide range of voluntary rating, awareness and dissemination programmes, as discussed in Table 16.

Voluntary and negotiated agreements involve a formal quantified agreement between a government body and a business or organization to increase the energy use efficiency of the organization. In the UK, Climate Change Agreements provide an 80% discount from the climate change levy for those sectors that agree to meet challenging targets for improving energy efficiency or reducing greenhouse gas emissions. In addition, *Display Energy Certificates* (DEC) mentioned previously as part of the EPBD requirement under regulatory instruments, represent a real opportunity and a visible commitment by the public sector to make the way they use their buildings more publicly accountable. DECs will allow visitors and staff to see just how much energy a building is using based on an actual energy audit of the building.

In the USA, a range of such programs exist to realize energy-saving opportunities provided by advancing a whole-building approach for construction and

TABLE 16
Information and Voluntary Instruments: UK, USA and India

Information and Voluntary Instruments			
Policy	**UK**	**USA**	**India**
Voluntary certification and labelling	Voluntary building certification system BREEAM ; ECOHOMES	Energy Star; LEED	TERI- GRIHA; LEED–India
Voluntary and negotiated agreements	Climate Change Agreements (CCA) provide an 80 per cent discount from the climate change levy	Programmes to promote EE. - Commercial Building Integration16 Rebuild America 17 Community-based partnerships Build America 18: Residential building integration:	
Public leadership programs	Display Energy Certificates	Federal Energy Management Programme 71	*Energy audits and retrofit of buildings Central and State government buildings*
Awareness raising, education, information campaigns	Key organisations: Carbon trust, Energy saving trust ACT on CO_2 Calculator to estimate CO_2 emissions for individual users	Key organisation: Office of Commercial High Performance Green Buildings	USAID – ECO III Manuals and codes, case studies and software. School programme National campaign on Energy conservation 2005 Award scheme for government and commercial buildings
Mandatory audit & energy management requirement	Display Energy Certificates for operational energy use Sub-metering of buildings as per Part L regulations	National benchmarking databases — RBECS; CBECS supported by target finder and portfolio manager online tools	Designated industries to have energy managers, Certification and training of energy auditors
Detailed billing and disclosure programs	Promotion of smart meters to see how much energy is being used	Revised guidelines for voluntary GHG Emissions reporting	Bills are based on individually metered buildings as a norm.

major renovation. Notably, programs such as the *Commercial Building Integration* program, *Rebuild America* program for community-based partnerships, and *Residential building Integration: Building America* allow DOE to help transfer the most energy-efficient building techniques and practices through regulatory activities, such as supporting the upgrade of voluntary (model) building energy codes. In India, as part of the public leadership program, energy audits and retrofits of central and state government buildings were carried out to employ energy reduction recommendations.

These programs are supported by a number of education and information campaigns in each country. In the UK, the Energy Saving Trust and the Carbon Trust are two key organizations, which maintain a strong package of support, advice, and information measures to help businesses improve their energy efficiency and take up of low carbon technologies. Another important information-based intervention by the government is *ACT on CO_2 Calculator*, an online tool that allows people to estimate their individual CO_2 emissions from simple house-related data and lifestyle choices.

Apart from the national databases, Voluntary GHG Emissions Reporting in the USA intends to encourage utilities, industries, farmers, landowners, and other participants to submit to an online registry comprehensive reports on their emissions and emissions reductions, including sequestration. In India, designated industries are now required to have energy managers and are encouraged to get energy audits by trained auditors.

6.5 Comparative Analysis of Policy Instruments for CO_2 Reduction

All of the instruments reviewed can achieve significant energy and CO_2 emissions savings; however, the costs per ton of CO_2-equivalent saved vary greatly. Based on a study of over 60 ex-post policy evaluation reports from about 30 countries (Koeppel and Urge-Vorsatz 2007), it was found that *control and regulatory mechanisms* are generally effective if enforced and the cost-effectiveness is dependent on the enforcement costs. Building codes and appliance standards were found to achieve the highest CO_2 emission reductions while appliance standards and energy-efficiency obligations were found to be among the most cost-effective policy tools. The UK leads the three countries in terms of regulatory control policies, while India is still in the process of developing first mandatory requirements for building energy performance.

Economic and market-based mechanisms are relatively new in the buildings sector. Energy performance contracting, cooperative procurement and energy-efficiency certificate schemes all were found to be effective tools in cutting CO_2 emissions from buildings at generally low cost.

Fiscal instruments and tax exemption policies can play a valuable role in stimulating the introduction of important energy efficiency technologies, new homes and commercial buildings. The UK has an array of fiscal instruments such as the climate change levy and enhanced capital allowance for technologies. It also has a series of fiscal grants, especially to support the fuel poor and elderly. Similarly, the USA operates a 'weatherization' programme which has been very successful and has improved energy efficiency of more than 5.5 million homes. India's fiscal grant programme is for introduction of low energy lighting in rural areas and policies are being considered for effective taxation of fuel.

Finally, *labeling and voluntary* programs can lead to large savings at low costs in buildings, while information program can also achieve significant savings and effectively accompany other policy measures. All three case study countries have a wide range of voluntary rating, awareness and dissemination programs. It has been found that these policies, while applied in many developed countries with favourable results, have rarely been pursued aggressively. As a result, in most developed countries the energy consumption in buildings is still increasing. Although some of this growth is offset by increased efficiency of major energy-consuming appliances, overall consumption continues to increase due to the growing demand for amenities, such as new electric appliances and increased comfort (Koeppel and Urge-Vorsatz 2007).

6.6 Cross-Fertilization of New-Build and Refurbishments

As new developments seek to achieve higher levels of CO_2 reduction (zero carbon buildings in the UK and carbon neutral in the USA), policy groups are also looking at ways in which new-build programs might cross-fund innovative steps in the existing stock to benefit both new-build and existing building stock. The concept is that on more difficult new-build sites, where practical solutions for zero-carbon or carbon-neutral are not viable, developers would be allowed to build to a more achievable level (low carbon or Code level 5 of Code for Sustainable Homes in the UK), and invest the savings into an independently-managed 'Community Energy Fund'. This funding source could help support district-scale refurbishment activity and the expansion of low carbon community energy networks from within new developments to existing surrounding buildings. Such a policy framework could be tested in rapidly-developing countries such as India, where 70% of the building stock will be built by 2030.

7. CONCLUSIONS AND KEY RECOMMENDATIONS

This paper has comparatively evaluated the building-related CO_2 measurement, benchmarking and reduction approaches available in the USA, UK and India, to share the lessons learnt in implementing CO_2 reduction policies in each of these countries. A comparative analysis was undertaken to evaluate the strengths and weakness of methods such as BREEAM/CSH in the UK, LEED in the USA, and TERI-GRIHA and LEED-India in India. The paper has also recommended robust performance-based standards (in terms of $kWh/m^2/year$ or $kgCO_2/m^2/year$) for reducing the energy consumption of existing buildings present in both developed and rapidly-urbanizing cities, which could be adopted by any developed or developing country. A range of policy instruments and measures are recommended to be successful in removing or lowering barriers and encouraging uptake of various CO_2 reduction strategies in existing buildings. Among these are appliance standards, building energy codes, appliance and building labelling, pricing measures and financial incentives, utility demand-side management programs, and public sector energy leadership programs including procurement policies. Because culture and occupant behaviour are major determinants of energy use in buildings, these policy approaches need to go hand in hand with programs that increase consumer access to information, awareness and knowledge.

It is realized that the UK is world-leading in its CO_2 reduction policy for buildings, but lacks good-quality bottom-up datasets of real energy consumption and CO_2 emissions in buildings. The USA, on the other hand, has excellent datasets at the EIA and DoE, but needs to have national-level policies and targets for CO_2 reductions from buildings. India is working on both policy and data collection given that energy data is quite polarized between urban and rural. In fact, the Bureau of Energy Efficiency is working with USAID's ECO-III programme to benchmark a range of commercial and institutional buildings — although the focus is primarily on energy efficiency and not CO_2 reduction. Hopefully, robust targets for CO_2 reduction and policies to achieve those targets will be set soon.

There is a broad array of widely accessible and cost-effective technologies and know-how that can abate CO_2 emissions in buildings. Although technologies have been greatly advanced during the past few decades, our understanding of the influence of culture, values, behavior or just energy use patterns is still very limited, and no quantification of the potentials and associated costs with the reduction opportunities in these areas have been conducted. We know that identical homes, with different occupants, can vary in energy use by a factor of two to three. We also know that how occupants make their homes or offices comfortable, through use of the heating system, doors, windows, lighting, the clothes they wear, etc. has an enormous effect on energy use. Operating a building well can reduce its carbon footprint much more than installing wind turbines or solar panels. At present, however, there is a lack of accurate information about exactly how much variation occupant behavior introduces to a building's energy consumption.

Moreover, while policies and projects have focused on climate change mitigation by reducing greenhouse gases, even the most optimistic projections indicate that some climate change is inevitable. The impacts of climate change on the built environment may include increased risks of flooding, overheating, storm damage and subsidence (IPCC 2007). It is important in this scenario to work towards adaptation and minimize the consequences of climate change. There is a need for adaptive policies to be mainstreamed through all development and environmental policies such as retrofitting existing building stock to ensure that it remains resilient to climate change impacts. Mitigation and adaptation are inherently linked processes, and both are essential for avoiding the worst impacts of climate change.

This paper demonstrates that the building sector must make available comprehensive building energy information to allow suitable analysis and efficiently plan energy policies for the future. In fact, *regularization of data collection and analysis* for the building sector can help quantify technology performance, its cost-effectiveness, role of barriers, identification of beneficiaries, and targeting of government and industry policies, programs, and measures. In that respect, studies developed by the EIA on the energy consumption of residential and commercial buildings in the USA are a valuable reference (EIA 2001, 2003, 2006, 2008a, 2008b).

It is hoped that the findings from this paper will help to expedite the process of achieving significant reductions in energy use and CO_2 emissions from the existing building stock by formulating policies which address the conventional barriers to implementation and increase the uptake of low carbon systems (heat pumps, solar hot water, solar PV, micro-combined heat and power, micro-wind) in buildings and cities. In the longer-term, the data archive of this study will be of immense value to all those with a stake in a low-carbon future be it for policy, practice or academic understanding. No doubt the ultimate aim is to make the global building stock become low-energy, low-carbon and more resilient to climate change effects.

References

All Party Urban Development Group. 2007. *Greening UK cities' buildings: improving the energy efficiency of our offices, shops and factories.* London: All Party Urban Development Group.

ASHRAE. 2008. *ASHRAE Building Energy Labeling Program: Promoting the Value of Energy Efficiency in the Real Estate Market.* Atlanta: Architecture 2030.

Baumert, K., Herzog T., and Pershing J. 2005. *Navigating the Numbers: Greenhouse Gas Data and International Climate Policy.* Washington: World Resources Institute.

Boardman, B. 2007a. "Examining the Carbon Agenda via the 40% House Scenario." *Building Research and Information* 35 (4): 363–78.

__________. 2007b. *Home truths: a Low Carbon Strategy to Reduce UK Housing Emissions by 80% by 2050.* A research report for The Co-operative Bank and Friends of the Earth, Oxford: University of Oxford's Environmental Change Institute.

Boonstra, C., and Thijssen I. 1997. *Solar Energy in Building Renovation.* London: James & James.

Bordass, B., and Leaman A. 2005). "Making Feedback and Post-Occupancy Evaluation Routine 1: A Portfolio of Feedback Techniques." *Building Research and Information* 33 (4): 347–52.

BRE. 2005. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings: SAP 2005.* Watford: Building Research Establishment.

BRE. 2010. *The Government's Standard Assessment Procedure for Energy Rating of Dwellings: SAP 2009.* Watford: Building Research Establishment.

Bruhns, H. R. et al. 2000. "Types, Numbers and Floor Areas of Nondomestic Premises in England and Wales, Classified by Activity." *Environment and Planning B: Planning and Design* 27 (1): 641–65.

Bureau of Energy Efficiency. 2006a. *Energising India: National Campaign on Energy Conservation 2007.* Delhi: Bureau of Energy Efficiency, Ministry of Power.

Bureau of Energy Efficiency. 2006b. *Energy Conservation of Building Code 2006.* Delhi: US Agency for International Development and International Institute for Energy Conservation.

CEA. 2009. *All India Electricity Statistics General Review 2009.* New Delhi: Central Electricity Authority, Ministry of Power.

Centre for Sustainable Energy, Association for the Conservation of Energy and Moore, R. 2006. *How Low: Achieving Optimal Carbon Savings from the UK's Existing Housing Stock.* Surrey: WWF-UK.

CLG (CLimate Leadership Group). 2005a. *Age Of Commercial and Industrial Stock: Local Authority Level 2004.* London: Communities and Local Government.

_______. 2005b. *Commercial and Industrial Floorspace and Rateable Value Statistics 1998–2004.* London: Communities and Local Government.

_______. 2006. *Review of the Sustainability of Existing Buildings. The Energy Efficiency of Dwellings: Initial Analysis.* London: Department for Communities and Local Government.

_______. 2008a. *Communities and Local Government. 2008. English House Condition Survey, 2006. Headline Report Decent Homes and Decent Places.* London: Communities and Local Government.

_______. 2008b. *Improving the Energy Efficiency of Our Buildings: A Guide To Display Energy Certificates and Advisory Reports for Public Buildings.* London: Communities and Local Government.

_______. 2008c. *Improving the Energy Efficiency of Our Buildings: A Guide to Energy Performance Certificates for the Construction, Sale and Let of Non-Dwellings.* 2nd edition, London: Communities and Local Government.

CLG and UKGBC. 2007. *Report on Carbon Reductions In New Non-Domestic Buildings.* London: Communities and Local Government.

CMIE. 200). *India's Energy Sector.* New Delhi: Centre for Monitoring Indian Economy.

Committee on Climate Change. 2008. *Building a Low-Carbon Economy: the UK's Contribution to Tackling Climate Change.* The First Report of the Committee on Climate Change, London: The Stationery Office.

Creyts, J. et al. 2007. *Reducing Greenhouse Gas Emissions: How Much at What Cost?* US Greenhouse Gas Abatement Mapping Initiative, Executive report: Mckinsey & Company.

DECC. 2009a. *Amendments to the Carbon Emissions Reduction Target.* Consultation, London: Department of Energy & Climate Change

_______. 2009). *Community energy saving programme (CESP).* Consultation, London: Department of Energy & Climate Change

_______. 2009c. *Heat and energy saving strategy.* Consultation, London: Department of Energy & Climate Change

DECC. 2011. *Annual Report on Fuel Poverty Statistics 2011.* A National Statistics publication. Available online at http://www.decc.gov.uk/assets/decc/Statistics/fuelpoverty/2181-annual-report-fuel-poverty-stats-2011.pdf accessed on 16/01/12.

DEFRA. 2007. *UK Energy Efficiency Action Plan 2007.* London: Department of Environment, Food and Rural Affairs.

DoE. 2004. *Building America: Research that Works.* Washington: Energy Efficiency and Renewable Energy, U.S. Department of Energy.

EIA (Energy Information Administration). 2001. *Residential Energy Consumption Survey (RECS).* Washington: Energy Information Administration, U.S. Department of Energy.

_______. 2003. *Commercial Buildings Energy Consumption Survey (CBECS).* Washington: Energy Information Administration, U.S. Department of Energy.

_______. 2006. *International Energy Outlook 2006.* Washington: Energy Information Administration, U.S. Department of Energy.

_______. 2008a. *2007 Buildings Energy Data Book.* Washington: Energy Information Administration, U.S. Department of Energy.

_______. 2008b. *Annual Energy Review 2007.* Washington: Energy Information Administration, U.S. Department of Energy.

English Heritage. 2004. *Building Regulations and Historic Buildings.* London: English Heritage.

EPA (Environmental Protection Agency). 2003. *Energy Star: The Power to Protect the Environment through Energy Efficiency.* Washington: US Environmental Protection Agency.

European Commission. 2010. *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).* Strasbourg: Official Journal of the European Union.

Foresight. 2008. *Powering our Lives: Sustainable Energy Management and the Built Environment.* London: Final Project Report, The Government Office for Science.

Fuel Poverty Advisory Group. 2008. *Sixth Annual Report.* London: Department for Business Enterprise & Regulatory Reform.

Gupta, R. 2005a. *Investigating the Potential for Local Carbon Dioxide Emission Reductions: Developing a GIS-Based Domestic Energy, Carbon-Counting and Carbon-Reduction Modeldepartment of Architecture.* Oxford: Oxford Brookes University.

_______. 2005b. "Investigating the Potential for Local Carbon Dioxide Emission Reductions: Developing a GIS-Based Domestic Energy, Carbon-Counting and Carbon-Reduction Model." Refereed Technical Paper. In *2005 Solar World Congress*. Orlando, Florida, USA.

_______. 2005c. "Leading by Example: Post-Occupancy Evaluation Studies of City Council-Owned Non-Domestic Buildings in Oxford to Assess the Potential for Reducing CO2 Emissions." In *Proceedings of the 24th International Conference on Passive and Low Energy Architecture (PLEA)*, 22-24 November 2007. Singapore.

_______. 2007. "A Review of Initiatives to Reduce Energy-Related CO2 Emissions from the City of Oxford: Past, Present And Future." In *ECEEE 2007 Summer study proceedings volume 1,* 437-447. 4–9 June 2007. Côte d'Azur, France: ECEEE.

_______. 2008. "Reducing Carbon Emissions from Oxford City: Plans and Tools." In *Urban Energy Transition,* ed. Droege P., 491–505. Oxford: Elsevier.

Gupta, R. and Chandiwala S. 2007. *How to Commission Sustainable Construction in Further Education Colleges.* Oxford: Seacourt Publishers.

Harvey, L. D. D. 2006. *A Handbook on Low-energy Buildings and District Energy Systems: Fundamentals, Techniques, and Examples.* London: James & James.

Hillman, M., Fawcett T., and Rajan, S. C. 2007. *The Suicidal Planet: How to Prevent Global Climate Catastrophe.* New York: Thomas Dunne Books.

IEA (International Energy Agency). 2004a. *CO_2 Emissions from Fuel Combustion,* 2004 edition. Paris: IEA.

_______. 2004b. *Energy Balances for OECD Countries and Energy Balances for Non-OECD Countries: Energy Statistics for OECD Countries and Energy Statistics for Non-OECD Countries,* 2004 edition. Paris: IEA.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva: IPCC.

Koeppel, S., and Ürge-Vorsatz D. 2007. *Assessment of Policy Instruments for Reducing Greenhouse Gas Emissions from Buildings.* Report for the UNEP-Sustainable Buildings and Construction Initiative. Budapest: Central European University.

Kumar, S. 2009. *Energy Efficiency in the Indian Building Sector: an Overview. USAID ECO-III Project.* Presentation given on 22 July 2009 at Environmental Change Institute, Oxford University, Oxford.

Kumar, S. et al. 2010. "Developing an Energy Conservation Building Code Implementation Strategy in India." In: *2010 ACEEE Summer Study on Energy Efficiency in Buildings*. 15-20 August 2010. Pacific Grove, California.

Lall, A. 2008. "Preventive Strategy for Air Conditioning: A Case for India." In: *Windsor conference 2008: Air-Conditioning and the Low Carbon Cooling Challenge*. 27-29 July. Windsor, UK.

LBNL. 2009. *Residential and Transport Energy Use in India: Past Trend and Future Outlook.* Berkeley, USA: Energy Technologies Division, Lawrence Berkeley National Laboratory.

Lowe, R. 2007. "Technical Options and Strategies for Decarbonizing UK Housing. *Building Research and Information* 35 (4): 412–25.

Majumdar, M. 2000. *Energy Efficiency in Green Buildings-An Integrated Approach to Building Design.* Delhi: The Energy & Resources Institute.

Mazria, E., and Kershner K. 2008. *The 2030 Blueprint: Solving Climate Change Saves Billions.* Santa Fe: Architecture 2030.

_______. 2009. *The Two-year, Nine-million-jobs Investment: The 2030 Challenge Stimulus Plan.* Santa Fe: Architecture 2030.

McKinsey & Company. 2009. *Environment and Energy Sustainability: An Approach for India.* Mumbai, India.

McNeil, M. A. et al. 2008. "Potential Benefits from Improved Energy Efficiency of Key Electrical Products: The Case of India." *Energy Policy* 36: 3467–76.

National Energy Technology Laboratory .2008. *2008 Buildings Energy Data Book.* Washington: Buildings Technologies Program, Energy Efficiency and Renewable Energy and U.S. Department of Energy.

Parker, D. 2009. "Very Low Energy Homes in the United States: Perspectives on Performance from Measured Data." *Energy and Buildings*.

Pe´rez-Lombard, L., Jose´ O., and Pout C. 2008. "A Review on Buildings Energy Consumption information." *Energy and Buildings* 40: 394–8.

Perez-Lombard, L. et al. 2009. "A Review of Benchmarking, Rating and Labelling Concepts within the Framework of Building Energy Certification Schemes." *Energy and Buildings* 41: 272–8.

Planning Commission. 2005. *Draft Report of the Expert Committee on Integrated Energy Policy.* Delhi: Government of India.

Pout, C. H. 2000. "N-DEEM: The National Nondomestic Buildings Energy and Emissions Model." *Environment and Planning B: Planning and Design* 27 (5): 721–32.

Pout, C. H., and MacKenzie F. 2005. *Reducing Carbon Emissions from Commercial and Pubcli Sector Buildings in UK.* Watford: Building Research Establishment.

Ravetz, J. 2008. "State of the Stock: What Do We Know about Existing Buildings and their Future Prospects?" *Energy Policy* 36: 4462–70.

Reddy, B. S. and Balachandra P. 2006. "Dynamics of Technology Shifts in the Household Sector: Implications for Clean Development Mechanism." *Energy Policy* 34: 2586–99.

SDC. 2006. *Stock Take: Delivering Improvements in Existing Housing.* London: Sustainable Development Commission.

The Carbon Trust. 2005. *The UK Climate Change Programme: Potential Evolution for Business and the Public Sector.* Technical report, London: The Carbon Trust.

Urge-Vorsatz, D. et al. 2007a. "Mitigating CO_2 Emissions from Energy Use in the World's Buildings." *Building Research and Information* 35 (4): 379–98.

Urge-Vorsatz, D., Koeppel S. and Mirasgedis S. 2007b. "Appraisal of Policy Instruments for Reducing Buildings' CO_2 Emissions." *Building Research and Information* 35 (4): 458–77.

USAID and LBNL. 2006. *Implementing End-Use Efficiency Improvements in India: Drawing from Experience in the US and other Countries.* Delhi: US Agency for International Development, Office of Environment, Energy and Enterprise.

USAID ECO-III project. 2008a. "Architecture Curriculum in India." A Background Paper, Delhi: US Agency for International Development ECO-III and Alliance to Save Energy.

________. 2008b. *ECBC Tip Sheet: Energy Simulation.* Delhi: US Agency for International Development ECO-III and Bureau of Energy Efficiency.

________. 2008c. *ECO-III Project Status and Accomplishments at a Glance.* Delhi: US Agency for International Development ECO-III.

________. 2008d. *Energy Assessment Guide for Commercial Buildings.* Delhi: US Agency for International Development ECO-III and Bureau of Energy Efficiency.

Voss, K. 2000. "Solar Energy in Building Renovation: Results and Experience of International Demonstration Buildings." *Energy and Buildings* 32: 291–302.

Way, M., and Bordass B. 2005. "Making Feedback and Post-Occupancy Evaluation Routine 2: Soft Landings: Involving Design and Building Teams in Improving Performance." *Building Research and Information* 33 (4): 353–60.

WCI (Western Climate Inititative). http://www.westernclimateinitiative.org/the-wci-cap-and-trade-program. [Online]. [Last accessed on 21 December 2009].

CHAPTER 4

Energy Consumption and CO_2 Emissions in Urban Counties in the United States with a Case Study of the New York Metropolitan Area

Lily Parshall,* Stephen A. Hammer, Kevin Robert Gurney

Summary

Urban areas are setting quantitative, time-bound targets for emissions reductions within their territories; designing local policies to encourage shifts toward cleaner energy supply, higher energy efficiency, and transit-oriented development; and exploring ways to participate in local carbon markets. These efforts require systematic estimates of energy consumption and emissions presented in a format and at a spatial resolution relevant for local governance. The Vulcan data product offers the type of high-resolution, spatial data on energy consumption and CO_2 emissions needed to create a consistent inventory for all localities in the continental United States. We use Vulcan to analyze patterns of direct fuel consumption for on-road transportation and in buildings and industry in urban counties. We include a case study of the New York Metropolitan Area.

*Corresponding author: lily.parshall@gmail.com

I. INTRODUCTION

Over the past decade, research studies on urban energy consumption and greenhouse gas (GHG) emissions have multiplied in recognition of the central role that cities play in shaping global energy demand as well as increasing urban leadership on climate change mitigation. Urban areas are setting quantitative, time-bound targets for emissions reductions within their territories; designing local policies intended to encourage shifts toward cleaner energy supply, higher energy efficiency, and transit-oriented development; and exploring ways to participate in local carbon markets. These efforts require systematic estimates of energy consumption and emissions presented in a format and at a spatial resolution relevant for local governance. Consistent estimates are also needed to understand how and why localities differ in their consumption profiles, develop appropriate benchmarks, analyze how different aspects of the urban environment interact with socio-demographic and market factors to shape patterns of energy use, and explore the distributional implications of different emissions-reduction policies. The Vulcan data product offers the type of high-resolution, spatial data on energy consumption and CO_2 emissions needed to create a consistent inventory for all localities in the continental United States (Gurney et al. 2008; Gurney et al. 2009). In Parshall et al. (2009), we describe our methodology for designing a national inventory at the local scale using Vulcan as the data source. In this paper, we present our results for urban counties in the continental United States and a case study of the New York Metropolitan Area (NY Metro Area). Our analysis focuses on direct final consumption of fossil fuels and associated CO_2 emissions, the portion of total emissions for which we could establish consistent, consumption-based estimates for both energy and emissions. We cover heating fuels (natural gas and LPG, distillate and residual fuel oil) and transport fuels (gasoline and diesel); the exclusion of electricity means that energy consumption and CO_2 emissions are highly correlated. We show that there is substantial variation in consumption patterns, both across urban areas, as well as within them.

II. PREVIOUS STUDIES

A range of different methodological approaches, accounting systems, urban boundaries, and datasets have been employed to study urban consumption patterns, with continuing disagreement on what portion of global emissions should be attributed to cities and/or urban households and how best to support urban energy and climate initiatives through local inventories. In the United States, many cities, towns, and counties have followed protocols established by ICLEI–Local Governments for Sustainability (ICLEI 2008). An advantage of ICLEI's approach is that local authorities complete the inventory for their own jurisdictional area using a consistent, consumption-based approach; on the other hand, it can be difficult to compare participating localities because they have some latitude in their choice of data, baseline year, and level of detail, and are free to decide whether and how to disseminate inventory data and results. Partially in response to this limitation, Brown et al. (2008) developed a consistent methodology for computing partial carbon footprints for the 100 largest US metropolitan areas, one of the most comprehensive consumption-based inventories available. The study, which covered residential consumption of electricity and heating fuels as well as highway transportation, found that the 100 largest metropolitan areas account for 65% of the US population, 76% of GDP, and 56% of carbon emissions (Brown et al. 2008).[1] The addition of commercial and industrial emissions might increase the urban share since the majority of these activities occur within metropolitan area boundaries.

We show in Parshall et al. (2009) that disaggregating US metropolitan areas into counties reveals substantial differences in the urban and rural portion of metropolitan areas. VandeWeghe and Kennedy (2007) disaggregate the Toronto Metropolitan Area into Census tracts and find that per-capita building-related emissions (electricity and fuel in residential, commercial, and industrial buildings) dominate within the urban core and transport emissions are higher outside the urban core. An older study of gasoline consumption found that in 1980 the typical resident of the New York Tristate Region used 335 gallons of gasoline per person, whereas a resident of New York City (5 boroughs) used 153 gallons per person, and a resident of New York County (Manhattan) used 90 gallons per person (Newman and Kenworthy 1989).

Whereas Brown et al. (2008) covered a few sectors for a large number of localities, Kennedy et al. (2009) developed complete emissions inventories for a small number of global cities. The study, which covered 10 major cities, estimates emissions based on several different accounting frameworks and suggests that a lifecycle (or industrial ecology) perspective offers a more complete view of the amount of energy consumed to meet urban demand. Ramaswami et al. (2008) offers a life-cycle perspective on urban-scale GHG emissions accounting. Dodman (2009) reviews existing literature on urban emissions, showing the diffi-

[1]The Brookings study attributed emissions associated with electricity production to the point of demand, an approach consistent with ICLEI's protocols, but one that can present particular methodological challenges because it requires estimating both total electricity consumption within a locality as well as the local fuel mix. In general, utility service boundaries do not match geopolitical boundaries, and the local fuel mix may differ substantially from the state fuel mix. In the Brookings study, a multi-step procedure was followed to derive consumption in each metropolitan area from data on utility service areas and then a statewide average fuel mix was applied to derive emissions (Brown et al. 2008).

culty of comparing studies based on differing perspectives and methodologies and from different parts of the world.

Dodman (2009), Newman and Kenworthy (1989), and Kennedy et al. (2009) all focus on major, international cities. In the United States, a growing share of the population lives in smaller and/or less dense urban areas, a trend attributable to the shift toward a more dispersed, service-oriented economy in the latter half of the 20th century (Kim, 2000). These urban areas, many of which rely on personal vehicles as the primary commute mode, are responsible for a growing share of energy demand. Along with Brown et al. (2008), our work is one of the few attempts to compare a large number of urban areas in the United States, rather than focusing on in-depth case studies of a small number of major cities.

Satterthwaite (2008) argues that the goal of urban emissions inventories should be to understand the role of urban lifestyles in different parts of the world, so inventories should include emissions embodied in goods and services. Quantifying embodied emissions is difficult, particularly given the globalized nature of the economy; examples of recent studies include Lenzen et al. (2004) and Weber and Matthews (2007). Ramaswami et al. (2008) shows that embodied emissions can be computed for key urban material inputs and that including such emissions helps to reconcile urban GHG inventories with national inventories.

Given the difficulty of measuring embodied energy, most quantitative studies estimate CO_2 emissions associated with consumption of energy for electricity, heat and transportation (and, in complete GHG inventories, emissions associated with waste, material production, etc.) within a territorial boundary. Based on this approach, the IEA estimated that 80% of primary energy demand in the United States is attributable to urban areas (IEA, 2008).[2] In our previous work, we found that between 37% and 81% of direct final consumption occurs in urban areas, depending on how these areas are defined and bounded in space (Parshall et al., unpublished manuscript 2009). Our focus on energy consumption within a territorial boundary is consistent with the perspective taken in most local climate, energy, and sustainability plans in the United States, which tend not to address embodied energy. Since we focus only on direct final consumption, the spatial location of energy consumption is the same as the spatial location of combustion, and thus CO_2 emissions. We estimate both energy consumption and emissions because the ability to distinguish between the energy and carbon intensity of different sectors can help local authorities analyze trade-offs between policies to reduce energy consumption and policies to reduce the carbon intensity of fuel use.

[2]The IEA methodology for computing US urban energy consumption is available on the World Energy Outlook website. The Vulcan data product was used in the US analysis, but the methodology was somewhat different from the methodology employed in Parshall et al. (2009), and the electricity sector was included. See: www.worldenergyoutlook.org/docs/weo2008/WEO_2008_Energy_Use_In_Cities_Modeling.pdf.

III. QUANTIFYING US URBAN ENERGY CONSUMPTION AND CO2 EMISSIONS

1. Definition of Urban

In Parshall et al. (2009), we evaluated a range of possible definitions of urban for use in local-scale energy and emissions inventories (see Table 1 below). We found that the county-based definition described in Isserman (2005) is most appropriate because counties are the highest resolution at which non-point source CO_2 emissions data are available, and because Isserman's definition incorporates the US Census thresholds for urban population density and size. Under this definition, the core portions of major cities in the United States tend to be defined as urban, but smaller cities and suburban regions tend to be excluded. For example, in California only the urban cores of San Francisco and Los Angeles are classified as urban, although the majority of California's counties are in metropolitan areas.

A county-based definition is also appealing because counties are the smallest political unit into which the entire US population can be divided (versus cities and towns which represent only a portion of the US population). Unlike counties, which are a recognized administrative division of state government, metropolitan areas do not play a formal role in governance, reducing the value of metropolitan-scale data to local policy makers. In Kennedy et al. (unpublished manuscript 2009a), the US cities included are defined as either counties (Los Angeles County, Denver County) or as a collection of counties (e.g. the 5 counties of New York City).

Isserman (2005) classifies 157 counties in the continental United States as urban. Although this represents just 5% of counties, it encompasses 45% of the population. By contrast, more than one-third of all counties are in metropolitan areas and more than 50% of the Census-designated rural population lives in metropolitan areas (Isserman, 2005). Also, note that 83% of the US population lives in metropolitan areas and the Census defines 78% of the US population as urban.

Some major US cities are located in counties that do not meet the Isserman (2005) urban criteria. Most notably, Maricopa County in Arizona, which contains the city of Phoenix, is not classified as an urban county. Although this county meets the population density criterion, its sizeable exurban population resulted in a designation of mixed urban, rather than urban. In the western United States, counties are less likely to be classified as urban because cities are often embedded into large counties; in the eastern United States, counties tend to be smaller in spatial extent, so many cities span multiple counties.

TABLE 1
Urban/Rural Definitions in the United States

United States	Definition	Spatial Units Used to Construct Boundaries	Advantages and Disadvantages of Classification System
Urban area (Census)	Urban cluster or urbanized area	Census block	Most accurate representation of where people live, but spatial boundaries are not aligned with administrative boundaries. Non-urban settlements not separated from one another.
Urbanized area	*>50,000 people, 1000/mi2 (386/km2)*		
Urban cluster	*>2,500 people, 500/mi2 (193/km2)*		
Metropolitan area	Core urban center + adjacent counties defined by the U.S. Office of Management and Budget (OMB)	County	Only scale at which GDP data are available, but metropolitan areas include the majority of the rural population and are not irreducible units since they are composed of counties.
Rural-urban continuum	Based on metro/ non-metro, adjacent to metro, and population	County	Improves on metro/non-metro classification of counties, but does not explicitly separate urban and rural population.
Rural-urban density code (Character)	**Based on urban-rural density mix and urban agglomeration**	**County**	**Classifies counties as urban or rural using density and agglomeration thresholds for Census urban areas as a starting point, so has the advantage of separating urban and rural areas at an administrative level, but counties may include multiple cities or towns.**
Commuting area	Based on commuting flow and classification of destination	Census tract	More accurate than metropolitan areas at separating integrated urban regions, but defined at the Census tract level, which is higher resolution than available energy/emissions data.
Urban influence code	Based on metro/micro, core/non-core, existence of town, and population	County	Improves on urban/rural continuum, but is a somewhat cumbersome classification system and still does not explicitly separate urban and rural counties.
Populated place	Political boundaries for cities, towns, and other incorporated places based on Census (2000)	Census block	Smallest unit for local jurisdictions and appealing from a local governance standpoint, but does not reflect a consistent definition of cities and has a higher resolution than available energy/emissions data.
Urban land cover	Areas of built-up land where large populations exist based on the urban layer of the DCW	None	Based on land use, but spatial boundaries are not aligned with administrative boundaries. Data on population, income, etc. do not match spatial boundaries.
International (selected)			
United Nations	Accepts urban definition of each country	Non-spatial	Authoritative international source for urban and rural population counts, but does not reflect a standard, international definition of urban.
GRUMP urban	Urban extents identified from night lights, DCW data, and other sources	Urban extents defined by analysis	Only international, spatial dataset with urban boundaries, but urban extents do not match other types of urban boundaries in the US.

The rural-urban density code (in bold) is the definition of urban used in this paper.
Source: Parshall et al. 2009.

2. Vulcan Data Product

We used the Vulcan data product, developed at Purdue University, to estimate energy consumption and related CO_2 emissions in each urban county. The Vulcan United States fossil fuel CO_2 emissions inventory covers the continental United States and contains hourly data for 2002, although we use aggregate annual data. Vulcan consolidates data from a wide variety of point, non-point, and mobile sources and quantifies these data in their « native » resolution (geocoded points, roads, counties) and on a regular 100-km^2 grid over the conterminous United States. Vulcan was originally conceived of as an inventory of fossil-based sources of carbon with scientific applications in carbon cycle modeling, so the dataset does not cover renewable energy or nuclear power, which together comprise approximately 28% of electricity supply and 5% of direct fuel consumption (e.g. for heating, industrial processes). Also, because the dataset attributes electricity emissions to the point of production, rather than the point of consumption, we exclude the electricity sector from our analysis. Since electricity generation comprises 34% of US nationwide GHG emissions, it is important to emphasize that our analysis covers only a portion of total emissions (US EPA 2009). The complete Vulcan methodology and data sources are described in Gurney et al. (2008) and Gurney et al. (2009). Our evaluation of the Vulcan data product and our methodology for extracting and processing relevant data are described in Parshall et al. (2009).

3. Energy and Emissions Accounting

In our analysis, we focus on direct fuel consumption and associated CO_2 emissions in urban areas. From an energy accounting perspective, we cover direct final consumption (i.e. delivered energy) within the local territory. From a greenhouse gas emissions accounting perspective, we cover IPCC Scope 1 CO_2 emissions associated with stationary combustion in the energy sector, but exclude utility-consumed fuel for electricity/heat generation. This approach is consistent with ICLEI's community-scale Scope 1, which covers « all direct emissions sources located within the geopolitical boundary of the local government » (in this case, each county) (ICLEI, 2008).

4. Sector/fuel Categories

We classified fuel consumption into the following categories: 1) gasoline consumption for on-road transportation, 2) diesel consumption for on-road transportation, 3) direct consumption of natural gas and LPG in buildings and industry, 4) direct consumption of distillate and residual fuel oil in buildings and industry. We excluded direct consumption of coal because its contribution to total direct fuel consumption is ~1%. Direct fuel consumption in the buildings and industry sector is primarily for heating and hot water, though natural gas also is used for cooking. In industrial buildings, fuel also is consumed in industrial production, processing, and assembly of goods. Emissions from Vulcan can be reported by sectoral (residential, commercial, industrial, transportation) and/or fuel divisions (coal, oil, natural gas). Rather than employ a dataset with sectoral categories, we used a dataset that covered all non-electricity emissions and where emissions were disaggregated by sub-fuel. This allowed us to convert between CO_2 emissions and energy consumption with reasonable accuracy, but it did not allow us to separate the residential sector from the commercial and industrial sectors.

5. Urban Energy and CO_2 Index

We compare urban counties on the basis of per-capita direct fuel consumption and CO_2 emissions, a subset of total urban CO_2 emissions. To facilitate rapid comparisons of groups of counties, we created an index that assigns a value of 100 to average per-capita consumption. The index value for each urban county is the percent of the average. For example, a county with twice the average per-capita consumption is assigned an index value of 200. Index values were computed for each sector/fuel combination based on both energy consumption (in GJ per capita) and CO_2 emissions (in metric tons per capita).

IV. PATTERNS OF US URBAN ENERGY CONSUMPTION AND CO_2 EMISSIONS

1. Total Direct Fuel Consumption

In the United States, 45% of the population lives in urban counties, which account for 37% of direct fuel consumption for on-road transportation, building heat, and heat used in industrial processes. Average per-capita CO_2 emissions were estimated to be 5.0 tons per capita for on-road transportation and 4.7 tons per capita for consumption of natural gas and heating oil in buildings and industry (Table 2).

TABLE 2
Average Per-Capita Fuel Consumption and CO_2 Emissions in Urban Counties

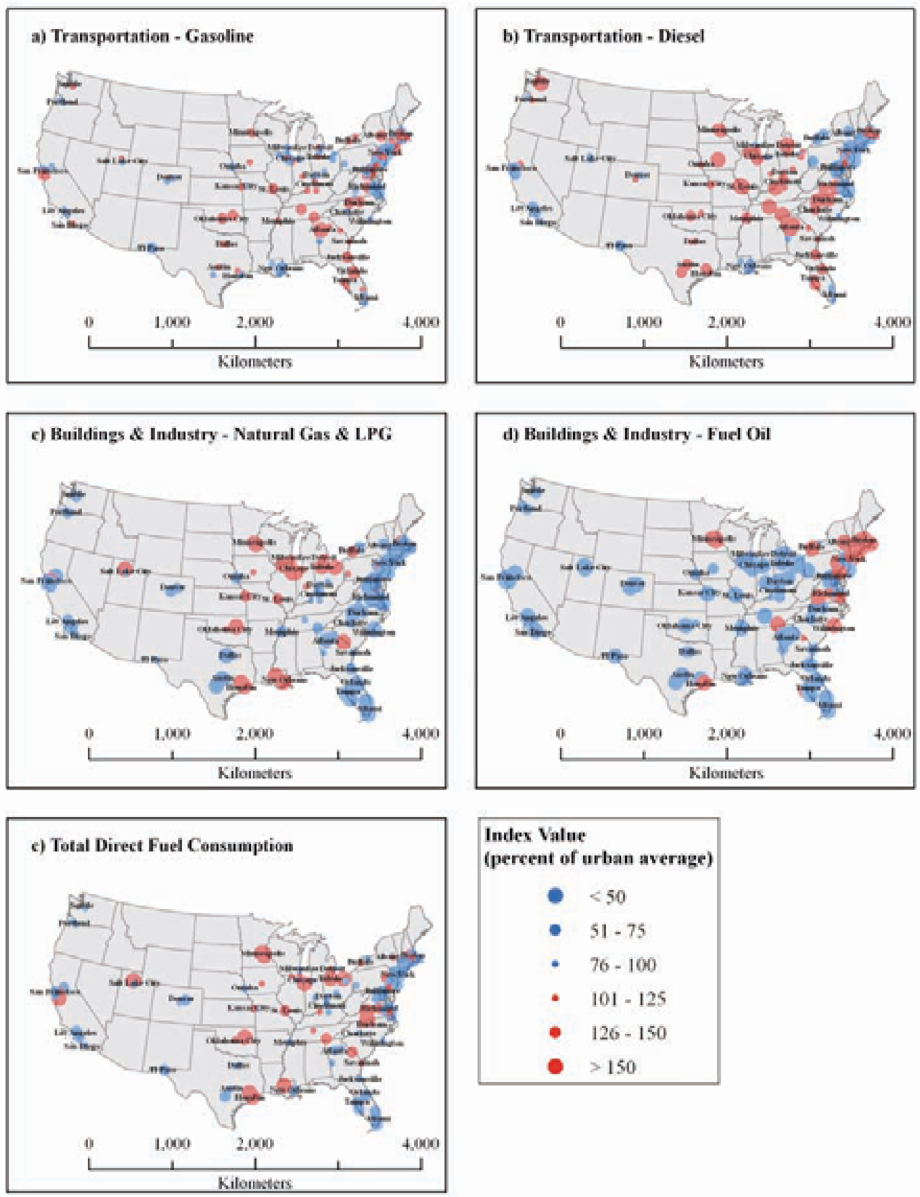
Urban Counties	Energy Consumption (GJ/capita)	Emissions (Mt CO_2/capita)	Emissions (% of per-capital total)
Natural gas and LPG	72.2	3.7	38.3%
Fuel oil	14.3	1.0	10.3%
Buildings and Industry	**86.5**	**4.7**	**48.6%**
Gasoline	61.6	4.1	42.5%
Diesel	12.4	0.9	8.9%
Transportation	**74.0**	**5.0**	**51.4%**
Direct Fuel Consumption	**160.9**	**9.7**	**100%**

*Note that the total population in urban counties in 2000 was 125,254,025 people.
Data sources: Vulcan data product for energy and emissions data, US Census 2000 for population data.

In Figure 1, we compare urban counties across the United States. These results reveal that, on a per-capita basis, southern and urban outskirt counties (i.e. urban counties that are economically dependent on another county's commercial center) tend to have the highest gasoline consumption, and southern and midwestern counties tend to have the highest diesel consumption. Midwestern counties tend to have the highest natural gas consumption, and northeastern counties tend to have the highest fuel oil consumption.

In the Appendix, we list index ranges for each urban county for selected sector/fuel categories.

FIGURE 1
CO_2 Emissions Associated with Direct Fuel Consumption in US Urban Counties

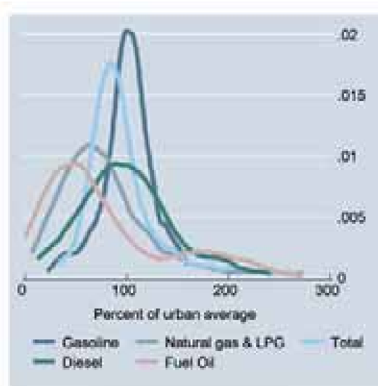


Only counties classified as urban by Isserman (2005) are shown. Note that each dot represents a single county. Some urban areas encompass several counties. *Data source:* Vulcan data product.

2. Transportation

In general, transportation results are easier to interpret than results for buildings and industry because they are not affected by regional differences in climate. Per-capita gasoline consumption is 12% lower in urban counties than the national average and, unlike some of the other sector/fuel categories, has a normal distribution and a small variance (Figure 2). In other words, urban areas differ less in their gasoline consumption compared with other fuels.

FIGURE 2
Distribution of CO_2 Emissions Index Values

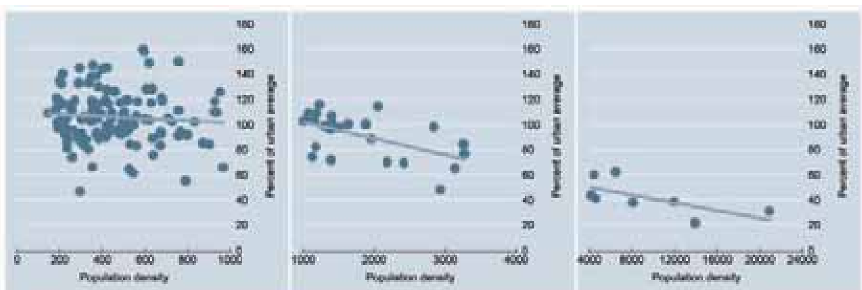


Mean for each variable is 100. Gasoline standard deviation is 66 versus 98 for diesel, 307 for natural gas & LPG, 863 for fuel oil, and 248 for the total (all fuels). Note that index values above 300 are not shown on the graph, although the distributions do include outliers with values > 300. *Data source:* Vulcan data product

Comparing the 157 urban counties reveals no relationship between population density and per-capita gasoline consumption for counties with fewer than 1000 people per square kilometer, but a relationship does emerge for higher-density areas (Figure 3). Note that there are just 33 counties with population density above 1000 people per square kilometer, and that 24 of these have an index value of less than 100. Among these 24 counties are many of the oldest and largest East Coast cities including New York City (5 boroughs), Philadelphia, Washington D.C. plus Alexandria and Arlington counties, Suffolk County (Boston), Baltimore City, and the counties containing Jersey City and Newark, NJ. The list, notably, does not include any counties in the south, southwest, or west (besides California). This supports the suggestion that current population density and access to public transit are an expression of when and why different urban economies developed

(Kim 2000), and that cities' historical economic development and timing of expansion have had a substantial impact on current consumption patterns. The lack of a relationship between population density and per-capita consumption and emissions at lower densities also suggests that the threshold above which there is a relationship between urban form and energy consumption may be relatively high in the United States, but additional, quantitative research is needed to confirm this preliminary finding.

FIGURE 3
Gasoline CO_2 Emissions Index Versus Population Density



a) Urban counties with population density less than 1000 people/km^2. b) Urban counties with population density between 1000 and 4000 people/km2. c) Urban counties with population density greater than 4000 people/km^2. Note that the urban county with the lowest population density has 147 people/km^2.
Data Sources: Vulcan data product and US Census 2000.

3. Buildings and Industry

Energy demand for space heating and cooling is strongly related to climate, and the United States spans desert to sub-arctic climate zones. In most cases, electricity is the primary source of energy for space cooling, but natural gas and fuel oil are the primary sources of energy for space heating. Since we do not cover electricity, urban counties in warmer climate zones tend to have lower consumption in buildings and industry compared with counties in cooler climates. Also, since we do not separate residential, commercial, and industrial consumption, counties with major commercial centers tend to consume more energy per capita than counties that are primarily residential. For example, New York County (Manhattan) has higher per-capita consumption than the outer boroughs of New York City.

Natural gas, which has lower CO_2 emissions per unit of energy compared with fuel oil, is the dominant source of heat in the United States. In some urban areas in the Northeast (e.g. New York, Boston, New Haven), fuel oil consumption is more than twice the per-capita average across all urban counties. In some cases, urban areas with high fuel oil consumption have low natural gas consumption (e.g. areas in Connecticut such as Hartford, Stamford, and New Haven). In other cases, per-capita natural gas consumption may be higher than per-capita fuel oil consumption even though the index value for fuel oil is higher (e.g. in the urban counties surrounding Boston). This is related to the differing distributions for natural gas and fuel oil (see Figure 2). In urban areas in the North-Midwest (e.g. Chicago, Minneapolis, Detroit), the great majority of heating demand is met with natural gas. With the exception of Minneapolis, these urban areas have high index values (>125) for natural gas and low index values (<75) for fuel oil. These results must be viewed with caution, as electricity is not included in the analysis and can be used in some states in place of natural gas for water heating and space heating. Ideally building energy-use from both electricity and natural gas is summed to assess efficiency.

V. ENERGY CONSUMPTION AND CO_2 EMISSIONS IN THE NEW YORK METROPOLITAN AREA

The NY Metro Area, which spans 23 counties in New York, New Jersey, and Pennsylvania, is one of the oldest, most densely-populated urban areas in the United States (Figure 4). The area's large population (18.8 million people) and economy ($1.1 trillion or about 8% of total US GDP in 2006), translate into higher-than-average total energy consumption and CO_2 emissions relative to other urbanized regions. On the other hand, per-capita emissions in the NY Metro Area's 19 urban counties are more than 25% lower, on average, than per-capita emissions in all US urban counties (Figure 5). In the 5 counties of New York City, per-capita emissions are less than 50% of the US urban average.

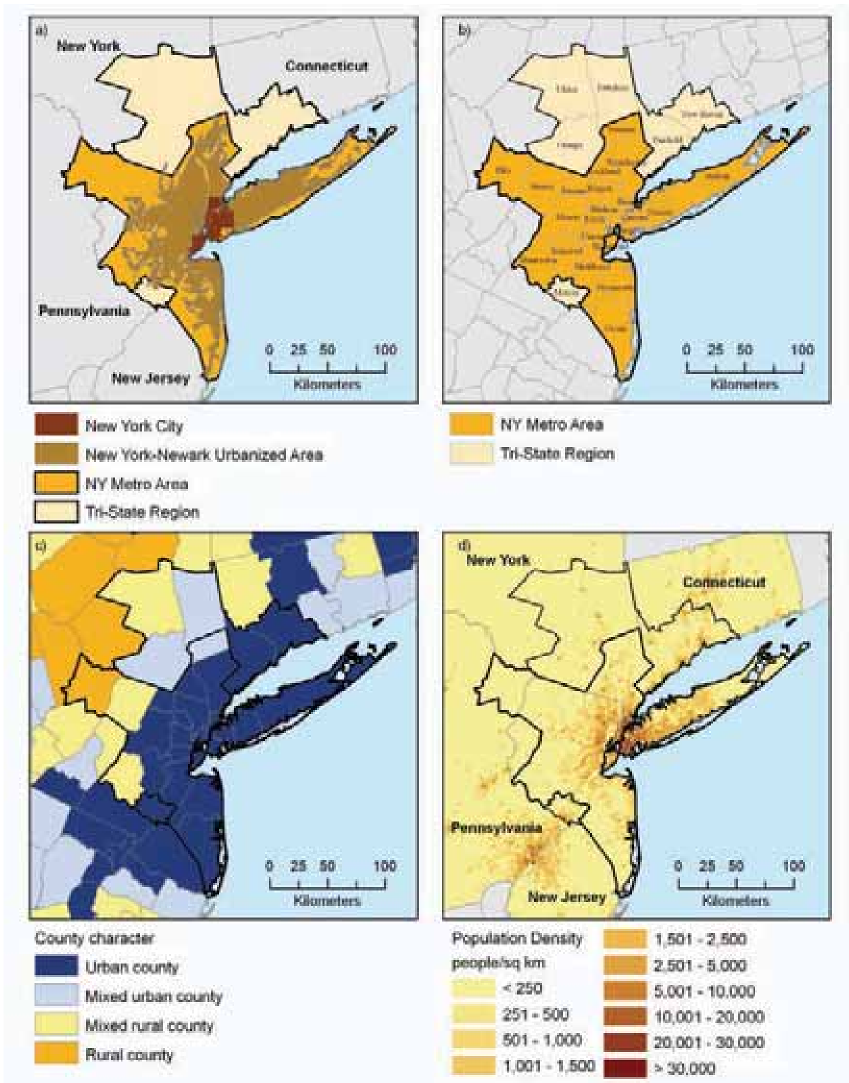
The New York Metropolitan Area is highly integrated with several other adjacent metropolitan areas. Together, this "Combined Statistical Area," which covers the portions of New York, New Jersey, Connecticut, and Pennsylvania within commuting distance of New York City, encompasses a total population of 21.9 million and is sometimes referred to as the "Tri-State Region." To avoid confusion between these two designations, we refer to the New York Metropolitan area as the "NY Metro Area" and the Combined Statistical Area as the "Tri-State Region." Within the Metro Area, 19 out of the 23 counties are classified as urban; within the Tri-State Region, 22 out of 29 counties are classified as urban.

1. Total Direct Fuel Consumption

We estimated total direct fuel consumption of 125.4 GJ/capita in the NY Metro Area and 78.0 GJ/capita in New York City (Table 3). Associated CO_2 emissions were estimated at 7.8 tons/capita and 4.8 tons per capita respectively. The difference is mainly driven by much lower per-capita gasoline consumption in New York City compared with the NY Metro Area. Our estimates agree well with results presented in City of New York (2008), Brown et al. (2008), and Kennedy et al. (unpublished manuscripts, 2009). In Appendix C, we present detailed comparisons of our results with these other studies.

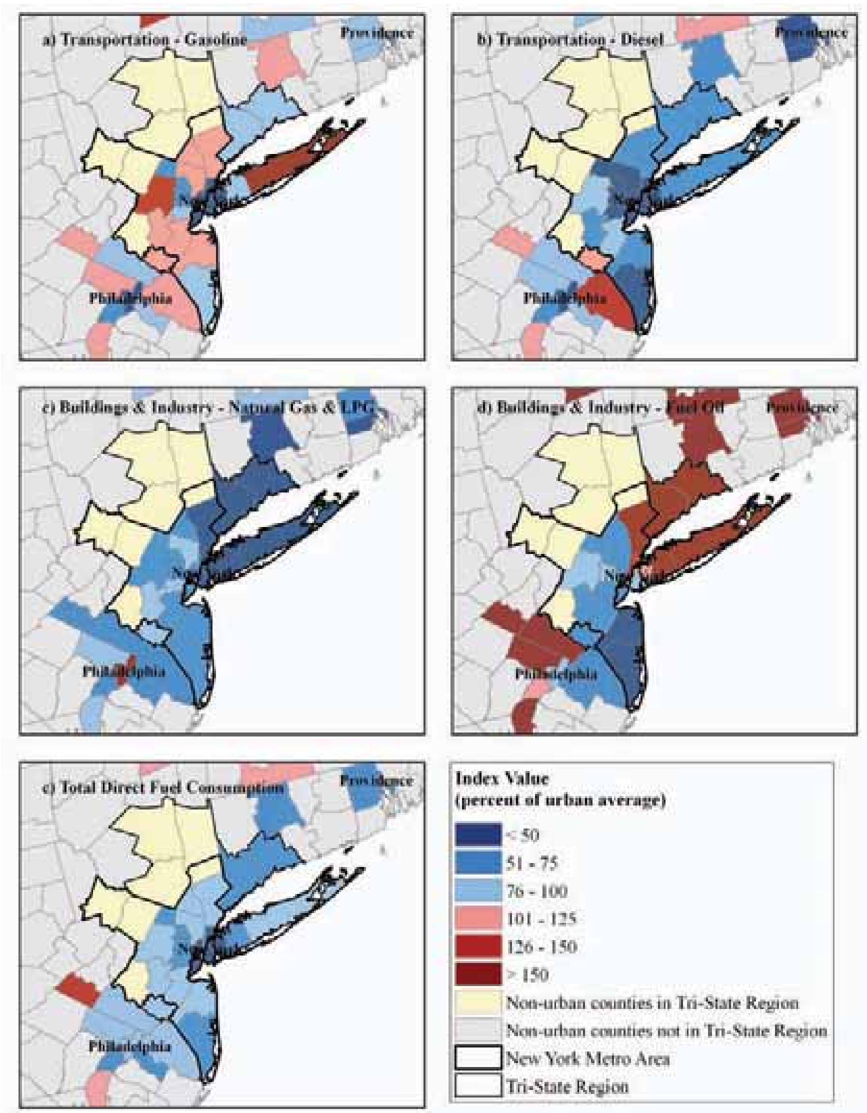
In Figure 6, we present total direct fuel consumption (in TJ of energy) in each county in the NY Metro Area. The counties are organized along the x-axis by population density, with higher-density counties on the left and lower-density counties on the right. In higher-density core counties, buildings and industry account for well over 50% of direct fuel consumption. In lower-density counties, gasoline consumption accounts for the majority of direct fuel consumption. Figure 6b shows the ratio between fuel consumption for buildings and fuel consumption for transportation against population density. In counties where the ratio is above 100%, building consumption dominates; in other counties, transportation consumption dominates. This effect would be dampened if electricity consumption were to be included in buildings and industry.

Figure 4
NY Metro Area and Tri-State Region



Data sources: Spatial boundaries from Tele Atlas North America, Inc. and ESRI; county character classification from Isserman (2005); population density from US Census 2000.

Figure 5
CO_2 Emissions Associated with Direct Fuel Consumption in Urban Counties in the NY Tri-State Region



Data sources: Vulcan data product.

Figure 6a
Direct Fuel Consumption in the NY Metro Area

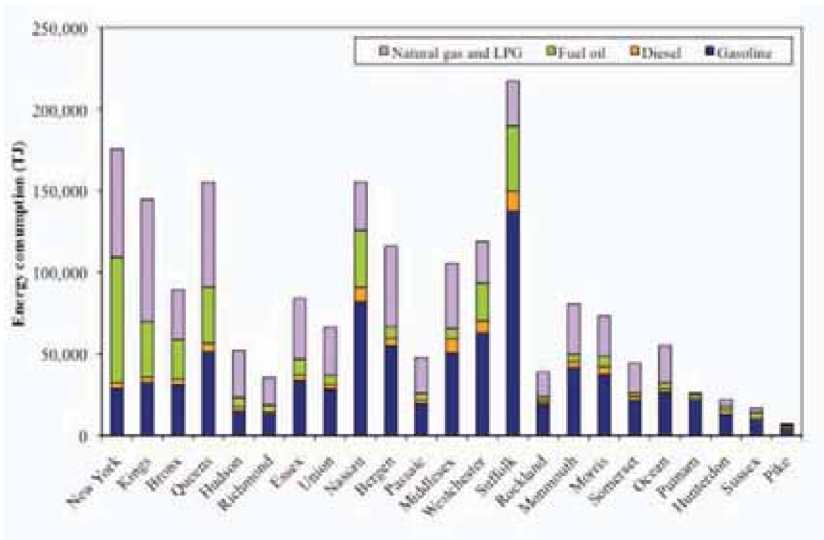
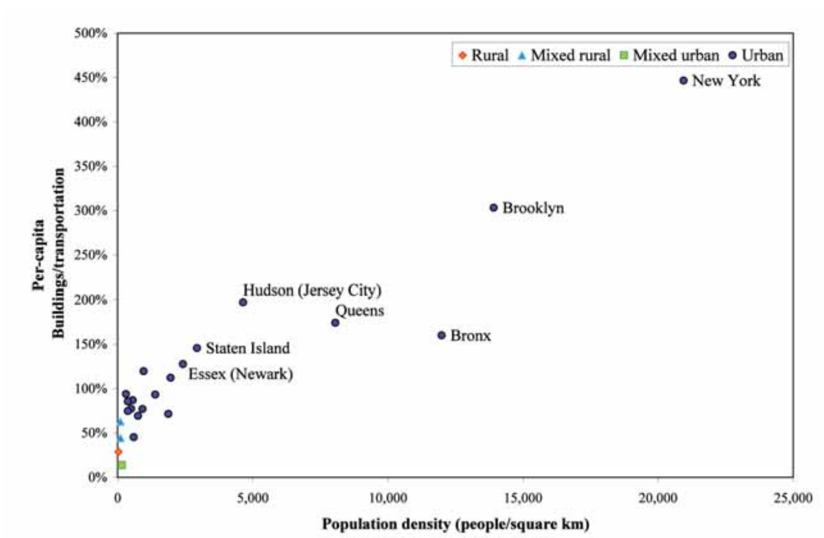


FIGURE 6b
Direct Fuel Consumption in the NY Metro Area



a) Values given are for total fuel consumption. Counties are organized in order of decreasing population density. All counties in the NY Metro Area are classified as urban with the exception of Putnam, Hunterdon, Sussex, and Pike. b) Values along the y-axis are per-capita buildings and industry fuel consumption (natural gas + LPG, fuel oil, coal) divided by per-capita transportation fuel consumption (gasoline, diesel). A value of 100% indicates that per-capita buildings and industry fuel consumption is equal to per-capita transportation fuel consumption. *Data sources:* Vulcan data product and US Census 2000.

TABLE 3
Average Per-Capita Direct Fuel Consumption and CO_2 Emissions for Subsets of Counties in the NY Metro Area Compared to the United States

Category (# of counties)	Buildings and Industry		Transportation	
	Energy Consumption (GJ/capita)	Emissions (Mt CO_2/capita)	Energy Consumption (GJ/capita)	Emissions (Mt CO_2/capita)
Rural counties (1)	35.1	2.2	121.2	8.2
Mixed rural counties (2)	50.3	3.0	98.5	6.6
Mixed urban counties (1)	32.9	2.2	238.7	15.9
Urban counties (19)	57.3	3.2	56.2	3.8
NY Metro Area (23)	**54.7**	**3.1**	**70.7**	**4.7**
Rural counties (1767)	136.7	7.5	147.3	9.9
Mixed rural counties (1013)	143.8	8.0	103.4	7.0
Mixed urban counties (145)	89.4	4.8	86.2	5.8
Urban counties (157)	86.5	4.7	74.0	5.0
United States (3108)	**133.8**	**7.4**	**125.8**	**8.5**
New York State (62)	**56.9**	**3.3**	**91.5**	**6.1**
Tri-State Area (29)	**53.2**	**3.0**	**73.1**	**4.9**
New York City (5)	**54.1**	**3.2**	**23.9**	**1.6**

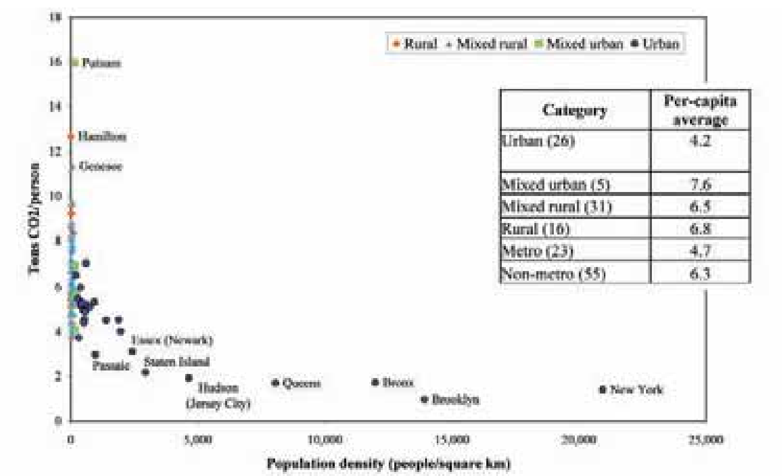
Data sources: Vulcan data product for energy and emissions data, US Census 2000 for population data. Note that the buildings and industry category covers only direct fuel consumption, so electricity is excluded.

2. Transportation

New York City has the largest public transit system in the United States and is one of the few American cities where the majority of the population relies on public transportation to travel to work (City of New York 2007). Whereas nationally, 90% of households own one or more private vehicles, in New York City only 44% own a car (City of New York 2007). Reliance on public transit within the city is reflected in low per-capita gasoline consumption; outside the city, regional commuter railroads and bus systems serve densely-populated suburbs, but personal vehicles are the primary mode of transportation for most people. This is reflected in higher per-capita gasoline consumption outside the core, for example in Nassau and Suffolk counties on Long Island. Throughout the NY Metro Area, per-capita diesel consumption is lower than the national average, perhaps as a result of higher overall population density and thus fewer freight kilometers driven per person.

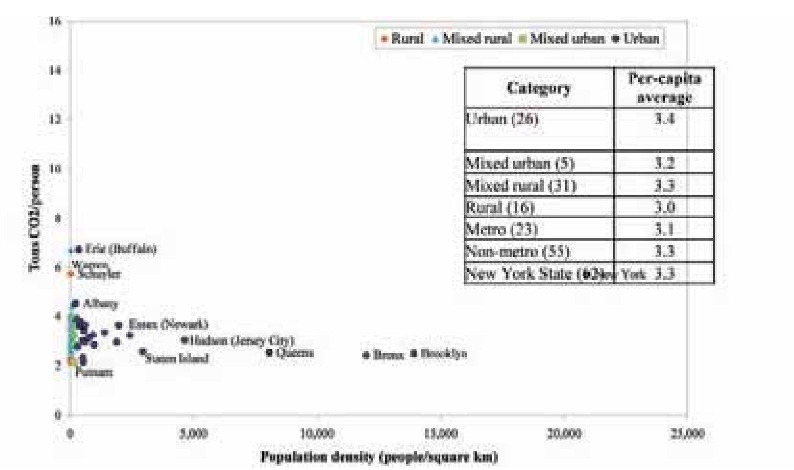
As Figure 7 confirms, only a small number of core urban counties are transit-oriented, and it is these counties that drive down the metropolitan area's average per-capita consumption. All counties, both urban and rural, in New York State, and the Tri-State Region (expanded metropolitan area) are shown on this plot to emphasize the distinction of a small sub-set of urban counties.

FIGURE 7
Population Density And Per-Capita CO_2 Emissions for Transportation All counties in New York State and the Tri-State Region are Shown



Data sources: Vulcan data product and US Census 2000.

FIGURE 8
Population Density and Per-Capita CO_2 Emissions for Buildings and Industry. All Counties in New York State and the Tri-State Region are Shown



Data sources: Vulcan data product and US Census 2000.

3. Buildings and Industry

A number of factors shape the region's energy consumption and emissions for buildings and industry. These include the region's temperate climate and service-based economy as well as high energy prices. Among the 50 largest metropolitan areas in the United States, New York ranks 20th in terms of heating-degree days (Siviak 2008) and has the largest regional economy, both of which have an upward effect on per-capita emissions from heating fuel. Nonetheless, the area has lower-than-average per-capita natural gas and fuel oil consumption in all (natural gas) and most (fuel oil) urban counties. With the exception of New York County (Manhattan), counties within the urban core (New York City plus Newark and Jersey City) have high population density and low per-capita consumption (Figure 8), indicating the possible importance of multi-family housing stock and smaller-than-average residential housing units. High energy prices and reduced demand for space heating associated with the urban heat island effect may also have a downward effect on per-capita heating fuel consumption, whereas small household size and high per-capita income may have an upward effect on per-capita consumption. Further research is needed to analyze interactions between these factors.

BOX 1

Comparison of New York City and NY Metro Area Estimates with Other Studies

Using the Vulcan data product, we estimated on-road transport emissions to be 1.6 tons per capita in New York City (5 boroughs) and building and industry emissions to be 3.2 tons per capita in 2002. These numbers agree well with the results of New York City's greenhouse gas emissions inventory (City of New York, 2008). Based on data in this report, New York City's on-road transport emissions were estimated to be 1.4 tons per capita. Building and industry emissions were estimated to be 5.9 tons per capita, including electricity (City of New York, 2008). The report indicates that 41% of city-wide emissions were associated with electricity versus 37% for heating fuels (including steam production); based on these figures, heating fuels account for approximately 2.8 tons of CO_2 emissions per capita. This estimate is 15% lower than our estimate, a reasonable discrepancy given the differing methodologies and baseline years. Our numbers also agree well with fuel consumption data received from the City of New York (personal communication, 2008), and the New York City estimates in Kennedy et al. (unpublished manuscripts, 2009), which were also derived from City of New York data. Using data provided by the City of New York (personal communication, 2008), we estimated on-ground transportation consumption to be 22.1 GJ/capita; using the Vulcan data product, we estimated emissions to be 23.9 GJ/capita. For buildings and industry, we estimated heating fuel consumption of 50.2 GJ/capita and 54.1 GJ/capita using City of New York and Vulcan data, respectively.

Brown et al. (2008) estimated CO_2 emissions associated with residential heating fuel to be 0.4 tons of carbon per capita, which is equivalent to 1.6 tons of CO_2 per capita. In New York City, the residential sector accounts for approximately 52% of heating fuel consumption. Assuming a similar ratio for the NY Metro Area, total heating fuel emissions might be approximately 3.2 tons/capita, an estimate that agrees well with our estimate of 3.1 tons/capita based on Vulcan data. Transportation estimates are not as close: Brown et al. (2008) estimate 3.0 tons/capita, and we estimate 4.7 tons/capita. A large part of this discrepancy is likely explained by the exclusion of non-highway transportation in Brown et al. (2008).

VI. CONCLUSIONS

Urban energy consumption is shaped by local geography and economic development, and by the history and culture of individual cities. A better understanding of consumption patterns can help individual urban areas move forward with locally-tailored energy efficiency and climate mitigation policy. A national inventory could also aid efforts to establish a formal role for local authorities in US energy and climate policy, which is currently dominated by federal and state governments.

Many cities have ambitious goals. For example, through PlaNYC, New York City has set a target of a 30% reduction in greenhouse gas emissions by 2030 (City of New York 2007). The city is pursuing a variety of technology shifts (e.g. promotion of combined heat and power and renewables) and policy changes (e.g. adaptation of the city's building code). The city is also attempting to strengthen local energy governance (e.g. arguing for more direct control over energy efficiency funding traditionally controlled by the state). Policies currently under debate at the federal and state level focus most heavily on the power sector and on vehicle fuel efficiency standards. Therefore, there is an opening for urban areas to target consumption of heating fuels, which are the largest source of energy demand in many cities in the northern half of the United States, and to promote building-level energy efficiency measures as a complement to national and state measures targeting power generation and/or distribution utilities.

A complete and regularly updated inventory could help to quantify the potential contribution of these and other urban initiatives. The Vulcan data product could become the basis of an effort to develop and institutionalize a national inventory at the local scale, although further research is needed to address some the limitations of Vulcan. For example, since Vulcan was originally intended to be a production-based inventory of carbon emissions, currently it is not possible to estimate urban electricity consumption, just electricity production. Because electricity use in buildings and in the urban rail transport sector is not incorporated, the Vulcan data product presents an incomplete picture of these sectors. A more wide-reaching effort would involve the development of internationally recognized standards for local-scale energy and emissions inventories, which could help to identify low-energy and low-carbon pathways in a range of different local settings.

References

Brown, M., Southworth F., and A. Sarzynski. 2008. *Shrinking the Carbon Footprint of Metropolitan America. Brookings Institute Metropolitan Policy Program*. http://www.brookings.edu/reports/2008/05_carbon_footprint_sarzynski.aspx. [Accessed February 2009].

City of New York. 2007. *PlaNYC: A Greener, Greater New York*. Mayor's Office of Long Term Planning and Sustainability. www.nyc.gov/html/planyc2030/html/downloads/download.shtml. [Accessed March, 2009].

______. 2008. *Inventory of New York City Greenhouse Gas Emissions, September 17, 2008.* http://www.nyc.gov/html/planyc2030/html/downloads/download.shtml. [Accessed May 2009].

Dodman, D. 2009. "Blaming Cities for Climate Change? An analysis of Urban Greenhouse Gas Emissions Inventories." *Environment and Urbanization* 21 (1): 185–201.

Gurney, K.R., Seib B., Ansley W., Mendoz D., Miller C., and M. Fischer. 2008. *Project Vulcan, Purdue University. Vulcan Science Methods Documentation*. http://www.purdue.edu/eas/carbon/vulcan/research.html. [Accessed October 2008].

Gurney, K.R., Mendoza D.L., Zhou Y., Fischer M.L., Miller C.C., Geethakumar S., and S. De La Rue Du Can. 2009. "High Resolution Fossil Fuel Combustion CO_2 Emission Fluxes for the United States." *Environmental Science and Technology* (Accepted May, 2009).

ICLEI — Local Governments for Sustainability (ICLEI). 2008. *International Local Government GHG Emissions Analysis Protocol Release Version 1.0*. http://www.iclei.org/index.php?id=8154. [Accessed February 2009].

International Energy Agency (IEA). 2008. *World Energy Outlook 2008.* OECD/IEA.

Isserman, A.M. 2005. "In the National Interest: Defining Rural and Urban Correctly in Research and Public Policy." *International Regional Science Review* 28: 465–99.

Kennedy, C., Steinberger J., Gasson B., Hansen Y., Hillman T., Havranek M., Pataki D., Phdungsilp A., Ramaswami A., and G.V. Mendez. 2009. "Greenhouse Gas Emissions from Global Cities." *Environmental Science and Technology* 43 (19): 7297–302.

Kim, S. 2000. "Urban Development in the United States, 1690-1990." *Southern Economic Journal*, 66 (4): 855–80.

Lenzen, M., Pade L., and J. Munksgaard. 2004. "CO_2 Multipliers in Multi-region Input-Output Models." *Economic Systems Research* 16 (4): 391–412.

Newman, P.W.G. and J.R. Kenworthy. 1989. "Gasoline Consumption and Cities: A Comparison of U.S. Cities with a Global Survey." *Journal of the American Planning Association* 55 (1): 24–37.

Parshall, L, Gurney, K., Hammer, S.A., Mendoza, D., Zhou, Y., and S. Geethakumar. 2009. "Modeling Energy Consumption and CO_2 Emissions at the Urban Scale: Methodological Challenges and Insights from the United States." *Energy Policy (in press, corrected proof)*, doi:10.1016/j.enpol.2009.07.006.

Ramaswami, A., Hillman T., Janson B., Reiner M., and G. Thomas. 2008. "A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories." *Environmental Science and Technology* 42 (17): 6455–61.

Satterthwaite, D. 2008. "Cities' Contribution to Global Warming: Notes on the Allocation of Greenhouse Gas Emissions." *Environment and Urbanization* 20 (2): 539–49.

Siviak, M. 2008. "Where to Live in the United States: Combined Energy Demand for Heating and Cooling in the 50 Largest Metropolitan Areas." *Cities* (in press).

United States Department of Commerce, BEA (Bureau of Economic Analysis). 2008. http://www.bea.gov/newsreleases/regiona;/gdp_metro/2008/gdp_metro0908.htm. [Accessed March 2009].

USEPA (United States Environmental Protection Agency). 2009. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 to 2008*. Executive Summary. http://epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010-Chapter-Executive-Summary.pdf. [Accessed March 2009].

VandeWeghe, J., and C. Kennedy. 2007. "A Spatial Analysis of Residential Greenhouse Gas Emissions in the Toronto Census Metropolitan Area." *Journal of Industrial Ecology* 11 (2): 133–44.

Weber, C.L., and H.S. Matthews. 2007. "Quantifying the Global and Distributional Aspects of American Household Carbon Footprint." *Ecological Economics* 66: 379–91.

APPENDIX
Urban Index Results by County

Urban County	State	Total		Bldgs & Industry (CO_2)		Transportation (CO_2)		Population (2000)	
		CO_2	Energy	Natural Gas	Fuel Oil	Gasoline	Diesel	Density	Total
Kings	**NY**	<50	<50	<50	76-100	<50	<50	13,922	2,465,326
Bronx	**NY**	<50	<50	<50	126-150	<50	<50	11,991	1,332,650
Queens	**NY**	<50	<50	<50	101-125	<50	<50	8,056	2,229,379
Hudson	**NJ**	<50	51-75	51-75	51-75	<50	<50	4,647	608,975
Richmond	**NY**	<50	<50	51-75	51-75	<50	<50	2,939	443,728
Poquoson City	VA	<50	<50	<50	<50	<50	<50	294	11,566
New York	**NY**	51-75	51-75	51-75	>150	<50	<50	20,943	1,537,195
San Francisco	CA	51-75	51-75	51-75	<50	51-75	76-100	6,447	776,733
Suffolk	MA	51-75	51-75	<50	>150	51-75	51-75	4,467	689,807
Washington	DC	51-75	51-75	76-100	51-75	76-100	51-75	3,267	572,059
Alexandria	VA	51-75	51-75	<50	76-100	76-100	51-75	3,258	128,283
Baltimore City	MD	51-75	76-100	76-100	76-100	51-75	<50	3,134	651,154
Essex	NJ	51-75	51-75	51-75	76-100	51-75	<50	2,419	793,633
Nassau	NY	51-75	51-75	<50	>150	76-100	51-75	1,881	1,334,544
Orange	CA	51-75	51-75	<50	<50	76-100	51-75	1,378	2,846,289
Delaware	PA	51-75	51-75	51-75	101-125	51-75	51-75	1,127	550,864
Passaic	**NJ**	51-75	51-75	51-75	51-75	51-75	<50	968	489,049
Los Angeles	CA	51-75	51-75	51-75	<50	76-100	51-75	903	9,519,338
Camden	**NJ**	51-75	51-75	51-75	51-75	76-100	76-100	873	508,932
Bristol	RI	51-75	51-75	<50	>150	51-75	<50	790	50,648
Alameda	CA	51-75	51-75	<50	<50	76-100	101-125	757	1,443,741
Montgomery	MD	51-75	51-75	51-75	<50	76-100	51-75	673	873,341
Virginia Beach	VA	51-75	51-75	<50	76-100	76-100	<50	642	425,257
Providence	RI	51-75	51-75	51-75	>150	76-100	<50	563	621,602
Fairfield	***CT***	51-75	51-75	<50	>150	76-100	51-75	533	882,567
New Haven	***CT***	51-75	51-75	<50	>150	76-100	51-75	518	824,008
Broward	FL	51-75	51-75	<50	<50	101-125	76-100	495	1,623,018
Sacramento	CA	51-75	51-75	<50	<50	76-100	101-125	480	1,223,499
Hartford	CT	51-75	51-75	<50	>150	101-125	51-75	445	857,183
Bexar	TX	51-75	51-75	<50	<50	76-100	126-150	421	1,392,931
Miami-Dade	FL	51-75	51-75	<50	<50	76-100	76-100	420	2,253,362
Kent	RI	51-75	51-75	<50	>150	76-100	<50	374	167,090
Hillsborough	FL	51-75	51-75	<50	<50	101-125	101-125	350	998,948
Orange	FL	51-75	51-75	<50	<50	126-150	101-125	337	896,344
Prince William	VA	51-75	51-75	<50	51-75	101-125	76-100	314	280,813
Ocean	**NJ**	51-75	51-75	51-75	<50	76-100	<50	312	510,916
El Paso	TX	51-75	51-75	76-100	<50	51-75	51-75	257	679,622
Arapahoe	CO	51-75	51-75	51-75	<50	76-100	76-100	236	487,967
Sarasota	FL	51-75	51-75	<50	<50	101-125	126-150	211	325,957
Palm Beach	FL	51-75	51-75	<50	<50	101-125	76-100	190	1,131,184

Urban Index Results by County, *continued*

Urban County	State	Total		Bldgs & Industry (CO_2)		Transportation (CO_2)		Population (2000)	
		CO_2	Energy	Natural Gas	Fuel Oil	Gasoline	Diesel	Density	Total
Philadelphia	PA	76-100	76-100	>150	76-100	<50	<50	4,151	1,517,550
Arlington	VA	76-100	51-75	<50	76-100	76-100	76-100	2,848	189,453
Cook	IL	76-100	76-100	101-125	<50	51-75	76-100	2,186	5,376,741
Union	**NJ**	76-100	76-100	76-100	51-75	76-100	<50	1,962	522,541
Milwaukee	WI	76-100	76-100	101-125	76-100	76-100	76-100	1,504	940,164
Denver	CO	76-100	76-100	76-100	<50	101-125	76-100	1,402	554,636
Bergen	**NJ**	76-100	76-100	76-100	51-75	101-125	<50	1,397	884,118
Pinellas	FL	76-100	76-100	<50	>150	101-125	76-100	1,191	921,482
Hampton City	VA	76-100	76-100	<50	76-100	101-125	51-75	1,079	146,437
De Kalb	GA	76-100	76-100	51-75	<50	126-150	>150	951	665,865
Dallas	TX	76-100	76-100	51-75	51-75	101-125	101-125	942	2,218,899
Fairfax	VA	76-100	76-100	<50	76-100	101-125	101-125	931	969,749
Middlesex	**NJ**	76-100	76-100	51-75	51-75	101-125	76-100	926	750,162
Marion	IN	76-100	76-100	101-125	<50	101-125	101-125	833	860,454
Hamilton	OH	76-100	76-100	76-100	<50	76-100	101-125	799	845,303
Franklin	OH	76-100	76-100	101-125	<50	76-100	101-125	768	1,068,978
Westchester	NY	76-100	76-100	<50	>150	101-125	51-75	757	923,459
Cobb	GA	76-100	76-100	51-75	<50	101-125	>150	683	607,751
Allegheny	PA	76-100	76-100	101-125	<50	76-100	51-75	671	1,281,666
Macomb	MI	76-100	76-100	101-125	<50	76-100	126-150	635	788,149
Clayton	GA	76-100	76-100	51-75	<50	126-150	>150	634	236,517
Prince Georges	MD	76-100	76-100	51-75	<50	101-125	76-100	629	801,515
Tarrant	TX	76-100	51-75	<50	51-75	101-125	101-125	622	1,446,219
San Mateo	CA	76-100	76-100	51-75	<50	126-150	76-100	607	707,161
Montgomery	PA	76-100	76-100	76-100	>150	101-125	76-100	601	750,097
Suffolk	**NY**	76-100	76-100	<50	>150	>150	51-75	599	1,419,369
Mercer	***NJ***	76-100	76-100	76-100	51-75	101-125	101-125	598	350,761
Rockland	**NY**	76-100	76-100	51-75	51-75	101-125	51-75	561	286,753
Multnomah	OR	76-100	76-100	51-75	51-75	76-100	101-125	546	660,486
Essex	MA	76-100	76-100	101-125	>150	51-75	51-75	544	723,419
Douglas	NE	76-100	76-100	101-125	101-125	76-100	76-100	532	463,585
Orleans	LA	76-100	76-100	101-125	<50	51-75	51-75	529	484,674
Gwinnett	GA	76-100	76-100	51-75	<50	101-125	>150	522	588,448
Summit	OH	76-100	76-100	101-125	<50	76-100	101-125	504	542,899
Monmouth	**NJ**	76-100	76-100	51-75	<50	101-125	51-75	503	615,301
Mecklenburg	NC	76-100	76-100	51-75	51-75	76-100	126-150	492	695,454
Baltimore	MD	76-100	76-100	51-75	51-75	101-125	76-100	485	754,292
Montgomery	OH	76-100	76-100	101-125	<50	76-100	101-125	470	559,062
Anne Arundel	MD	76-100	76-100	<50	76-100	126-150	76-100	457	489,656
Shelby	TN	76-100	76-100	51-75	<50	101-125	126-150	445	897,472

Urban Index Results by County, *continued*

Urban County	State	Total		Bldgs & Industry (CO_2)		Transportation (CO_2)		Population (2000)	
		CO_2	Energy	Natural Gas	Fuel Oil	Gasoline	Diesel	Density	Total
Salt Lake	UT	76-100	76-100	76-100	<50	76-100	76-100	434	898,387
Monroe	NY	76-100	76-100	51-75	76-100	101-125	51-75	428	735,343
Jackson	MO	76-100	76-100	101-125	<50	76-100	101-125	415	654,880
Seminole	FL	76-100	76-100	<50	<50	126-150	126-150	401	365,196
Lake	OH	76-100	76-100	101-125	<50	76-100	101-125	382	227,511
Morris	**NJ**	76-100	76-100	51-75	76-100	126-150	76-100	381	470,212
Somerset	**NJ**	76-100	76-100	76-100	51-75	101-125	51-75	380	297,490
Bucks	PA	76-100	76-100	51-75	>150	76-100	76-100	375	597,635
Kenton	KY	76-100	76-100	51-75	51-75	101-125	126-150	358	151,464
Jefferson	LA	76-100	76-100	>150	<50	51-75	51-75	355	455,466
Duval	FL	76-100	76-100	51-75	<50	126-150	126-150	351	778,879
Muscogee	GA	76-100	76-100	76-100	51-75	76-100	76-100	325	186,291
Clarke	GA	76-100	76-100	51-75	<50	101-125	101-125	324	101,489
Travis	TX	76-100	76-100	<50	<50	101-125	126-150	303	812,280
King	WA	76-100	76-100	51-75	51-75	101-125	>150	303	1,737,034
New Hanover	NC	76-100	76-100	<50	>150	76-100	76-100	301	160,307
Kane	IL	76-100	101-125	126-150	<50	76-100	101-125	300	404,119
Schenectady	NY	76-100	76-100	51-75	101-125	101-125	51-75	272	146,555
Jefferson	CO	76-100	76-100	51-75	<50	76-100	101-125	264	527,056
San Diego	CA	76-100	76-100	76-100	<50	101-125	76-100	256	2,813,833
Washington	OR	76-100	76-100	76-100	51-75	76-100	76-100	236	445,342
St Joseph	IN	76-100	76-100	101-125	<50	76-100	76-100	224	265,559
Chesapeake	VA	76-100	76-100	<50	76-100	101-125	51-75	222	199,184
Barnstable	MA	76-100	76-100	51-75	>150	101-125	101-125	208	222,230
Burlington	NJ	76-100	76-100	51-75	51-75	101-125	126-150	202	423,394
Sarpy	NE	76-100	76-100	51-75	51-75	76-100	101-125	193	122,595
St Charles	MO	76-100	76-100	76-100	<50	101-125	>150	187	283,883
St Louis City	MO	101-125	101-125	126-150	51-75	101-125	>150	2,055	348,189
Norfolk City	VA	101-125	76-100	51-75	126-150	76-100	51-75	1,628	234,403
Portsmouth	VA	101-125	76-100	<50	126-150	51-75	<50	1,387	100,565
Wayne	MI	101-125	101-125	126-150	<50	76-100	126-150	1,300	2,061,162
Du Page	IL	101-125	101-125	126-150	<50	101-125	126-150	1,045	904,161
Jefferson	KY	101-125	101-125	76-100	76-100	101-125	>150	679	693,604
Norfolk	MA	101-125	101-125	76-100	>150	126-150	126-150	619	650,308
Fulton	GA	101-125	101-125	76-100	<50	>150	>150	591	816,006
Petersburg	VA	101-125	101-125	<50	101-125	101-125	>150	567	33,740
Lake	IL	101-125	101-125	126-150	<50	76-100	126-150	534	644,356
Oakland	MI	101-125	101-125	101-125	<50	101-125	>150	511	1,194,156
Davidson	TN	101-125	101-125	76-100	<50	126-150	>150	422	569,891
Henrico	VA	101-125	76-100	<50	101-125	126-150	76-100	421	262,300
New Castle	DE	101-125	101-125	76-100	>150	101-125	101-125	416	500,265

Urban Index Results by County, *continued*

Urban County	State	Total		Bldgs & Industry (CO_2)		Transportation (CO_2)		Population (2000)	
		CO_2	Energy	Natural Gas	Fuel Oil	Gasoline	Diesel	Density	Total
Wyandotte	KS	101-125	101-125	126-150	101-125	101-125	101-125	396	157,882
Johnson	KS	101-125	101-125	101-125	51-75	101-125	101-125	367	451,086
Oklahoma	OK	101-125	101-125	101-125	<50	126-150	126-150	357	660,448
Fayette	KY	101-125	76-100	76-100	51-75	101-125	101-125	356	260,512
Erie	NY	101-125	101-125	126-150	>150	101-125	76-100	353	950,265
Durham	NC	101-125	101-125	51-75	51-75	126-150	>150	292	223,314
Forsyth	NC	101-125	76-100	<50	51-75	126-150	>150	289	306,067
Hampden	MA	101-125	101-125	76-100	>150	76-100	101-125	280	456,228
Polk	IA	101-125	101-125	101-125	51-75	101-125	>150	247	374,601
Will	IL	101-125	101-125	>150	<50	76-100	126-150	230	502,266
Albany	NY	101-125	101-125	76-100	>150	126-150	76-100	215	294,565
Winnebago	IL	101-125	101-125	>150	<50	76-100	126-150	209	278,418
Chatham	GA	101-125	101-125	76-100	51-75	101-125	101-125	185	232,048
Richmond City	VA	126-150	126-150	76-100	126-150	101-125	76-100	1,232	197,790
Newport News	VA	126-150	101-125	51-75	>150	101-125	51-75	1,006	180,150
St Louis County	MO	126-150	126-150	101-125	<50	126-150	>150	758	1,016,315
Middlesex	MA	126-150	>150	>150	>150	76-100	76-100	673	1,465,396
Contra Costa	CA	126-150	126-150	>150	51-75	101-125	51-75	495	948,816
Lehigh	PA	126-150	101-125	51-75	>150	101-125	101-125	350	312,090
Richmond	GA	126-150	>150	>150	101-125	101-125	101-125	235	199,775
Hamilton	TN	126-150	126-150	51-75	>150	126-150	>150	208	307,896
York	VA	126-150	126-150	>150	51-75	126-150	76-100	202	56,297
Cuyahoga	OH	>150	>150	>150	<50	76-100	76-100	1,183	1,393,978
Ramsey	MN	>150	>150	101-125	>150	101-125	126-150	1,160	511,035
Harris	TX	>150	>150	>150	<50	101-125	126-150	730	3,400,578
Hennepin	MN	>150	>150	126-150	>150	101-125	126-150	711	1,116,200
Lynchburg City	VA	>150	>150	76-100	>150	76-100	126-150	512	65,269
Lucas	OH	>150	>150	>150	<50	101-125	101-125	511	455,054
Santa Clara	CA	>150	126-150	51-75	51-75	101-125	76-100	505	1,682,585
Danville City	VA	>150	126-150	51-75	>150	76-100	126-150	429	48,411
Lake	IN	>150	>150	>150	51-75	101-125	101-125	376	484,564
Tulsa	OK	>150	>150	>150	76-100	126-150	101-125	374	563,299
E Baton Rouge	LA	>150	>150	>150	<50	76-100	76-100	335	412,852
Galveston	TX	>150	>150	>150	>150	76-100	101-125	235	250,158
Dakota	MN	>150	>150	>150	>150	101-125	126-150	235	355,904
Davis	UT	>150	>150	>150	<50	101-125	76-100	147	238,994

Bold counties are in the NY Metro Area. Bold, italic counties are in the Tri-State Region but not the NY Metro Area. With the exception of total energy, all index values were computed on the basis of per-capita emissions of CO2 associated with direct fuel consumption. Total energy was computed on the basis of per-capita direct fuel consumption (measured in GJ). Data sources: Vulcan data product and US Census 2000.

CHAPTER 5

Mitigating Urban Heat Island Effect by Urban Design: Forms and Materials

Julien Bouyer,* Marjorie Musy, Yuan Huang, Khaled Athamena

Summary

This paper provides a synthesis of three complementary research works that contribute to the same objective: proposing solutions to reduce building energy consumption by modifying local climate. The first work explores urban forms: it proposes methods to describe them and analyze the climatic performances of classified urban forms. The second one focuses on one parameter of direct relevance to urban heat island phenomenon: the surface albedo. The albedo of a city or a district depends on surfaces' arrangement, materials used for roofs, paving, coatings, etc., and solar position. The third one proposes a simulation tool that permits to evaluate the impact outdoor urban environment on buildings' energy consumption. This analysis permits us to propose morphology indicators to compare the relative efficiencies of different typologies. The conclusion discusses the relevance of using indicators (based on physics or morphology, related to site or to built form) in urban design process and proposes a methodology to produce indicators.

*Corresponding author: julien.bouyer@developpement-durable.gouv.fr

1. INTRODUCTION

In most countries, thermal regulations may enable to control building energy consumption. However, we sometimes dispose of efficient techniques adapted to climate and to architectural culture. For example, buildings' envelopes are designed to better insulate indoor climate from outdoor climate by controlling heat and mass transfers between them, yet these practices sometimes omit to consider the indirect effect that envelopes have on building energy consumption. Indeed, the radiative characteristics of the buildings' envelope and the geometrical arrangement of them in the city play an important role in the urban heat island phenomenon. This one factor may impact building energy consumption, because of the increase of air and surface temperatures. In addition, this may lead to uncomfortable and unhealthy situations for inhabitants in summer. The causes and effects of urban climates and heat islands are diverse (Akbari 2001; Oke 1987; Santamouris 2001):

- less evapotranspiration because of mineralization of cities,
- more solar energy absorption due to lower albedo,
- less nocturnal infrared radiative loss due to the building density,
- less convection because of reduced air velocity caused by higher urban surface roughness,
- higher anthropogenic loads partly due to air conditioner rejects.

Their interactions are complex and the effect of the different design parameters that play a role in these phenomena, in particular urban form, can be contradictory.

This paper gives a synthesis of three complementary research works in progress that are contributing to the same objective: proposing solutions to reduce building energy consumption by corrective actions that modify the local climate.

The first work explores classified urban forms. It proposes methods to describe urban forms and then analyze the climatic performances of those classified forms. Based on this study, it is possible to propose morphology indicators that compare the relative efficiencies of different typologies. The urban form typologies described and the climatic performance indicators developed can become beneficial tools and references to assist urban design. As such, research results are translated into design guidelines in order to express optimal urban form guidelines based on typology and morphology indicators. This is an important process that allows for designers to more-easily understand research results and applications of the research.

The second one focuses on solar energy absorption and surface albedo. The albedo of a city or a district depends on the surfaces' arrangement, materials used for roofs, paving, coatings, and solar position. We study these dependencies through the calculation of the albedo for different urban blocks in the case of a real urban project located in Lyon, France. This study can be used to increase the awareness of urban planners, designers and decision makers on the importance of the choice of coating, paving and roof materials not only for their aesthetics but also for their function - i.e. their effect on local climate and indirectly on building energy consumption.

For these urban blocks, several morphology parameters have been evaluated and correlations drawn between them through calculated albedos. From these correlations, we propose a simple indicator that can be used to characterize the radiative contribution of a district to urban heat island effect. This indicator, due to its simplified formulation, could be classified as a decision-support tool for early stages of the project. The tool allows to compare different projects with an objective criterion, eventually integrated in a multi-criteria approach.

The third work proposes a complete simulation tool that permits to evaluate the impact of outdoor urban environment on buildings' energy consumption. The simulation tool is a physics based code that includes models for thermal and hydrous behavior of walls, grounds, trees and water ponds. The model permits simulation of airflows, including thermal and hydrous effects and evaluates the energy balance in buildings taking into account the local climate contrary to what is usually done when using climate data from weather stations (often located near airports). This tool, dedicated to research, allows to study the complex interactions between the phenomena implied in Urban Heat Island (UHI), the buildings' construction and use, and their related impact on the energy demand and consumption.

The conclusion integrates the three study results to discuss the cumulative intake of the used methods and indicators, which deal with different degrees of knowledge (based on physics or morphology, related to site or to built form) in the urban design process.

2. URBAN FORM AND ENERGY PERFORMANCE

It has been proved that urban forms affect urban microclimate (Givoni 1989), and that these changes in the urban environment result in modified building energy consumption (Santamouris 2001). As Oke (1984) argued, urban climatology can become a more predictive science in which findings can be of direct value in urban planning and design. Mills (1999) proposed that by examining the relationship between urban forms and climate, one could employ the results of urban climatology into urban design guidelines. Therefore, for mitigating urban heat island effect by urban design, our primary work on the research of urban forms is to systematically collect and comb all urban form factors that may impact building energy consumption through microclimate.

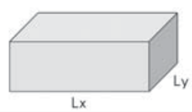
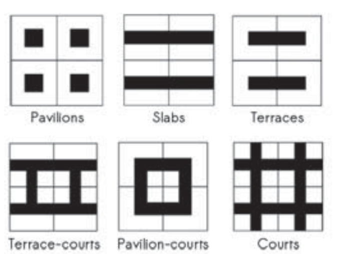
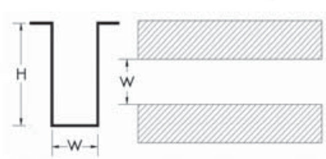
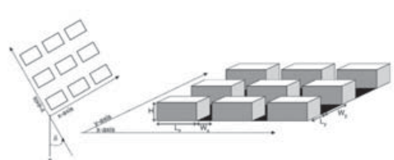
2.1 Method

Based on literature review, we collect studies that have proved the impact of urban forms on climatic parameters and on building energy consumption. Then we extract the part of urban form analysis from these studies, and classify the urban form factors with different scales. This is followed by analysis and introduction through two methods: 1) urban form typology and 2) morphological indicators. Then we study and explore the derivative urban form patterns and compare/quantify these urban forms patterns with the corresponding morphological indicators.

2.2 Results

The framework established for the urban form factors covers the scales from single building to urban block. We establish an elementary framework (Table 1) that is

TABLE 1
Basic Frame of the Proposed Urban Form Factors

SCALE	FORM PATTERN	RELATED INDICATORS
Single building		• shape ratio (S/V) • main façade orientation • glazing ratio • ratio of side (Lx/Ly)
Generic built form	 *(Ratti et al. 2003)*	• plot ratio • site coverage • shape ratio (S/V) • total surface area • sky view factor (SVF)
Street		• aspect ratio (H/W) • street orientation
Urban block/district	 *(Panao et al. 2008)*	• floor space index (FSI) • grid azimuth (δ) • number of floors (n) • base block dimension (Ly) • building depth ratio (l=Lx/Ly) • directional aspect ratio (H/Wx ; H/Wy) • directional street width ratio (w=Wx/Wy)

composed of basic urban form patterns and morphological indicators at different scales. Data is then cited and analyzed to accurately represent derivative urban form patterns and morphological indicators as a result of this basic framework.

2.2.1 Single Building

Taking rectangular shape as the basic form pattern, we proposed shape ratio (S/V), main façade orientation and glazing ratio as the basic morphological indicators. They have been proved their importance for building energy consumption impact (Fu 2002).

2.2.2 Generic Built Form

Generic built form is a basic single building on a little plot for an urban block arrangement. The study of Ratti (2003) presented that the generic built forms are from simplified synthetic urban fabric. Under the same plot ratio, he proposed six archetypal forms linking with several basic indicators (Table 1); especially the ratio of passive to non-passive floor area that indicated the impact on building energy consumption. Brown (2001) defined directional space ratio (H_1/W_1, H_2/W_2 etc.) for court space to analyze the relation between directional H/W and court wind, incident solar radiation. Ratti (2003) set up three generic built forms (Fig.1) for the research in an arid climate based on the six archetypal forms.

2.2.3 Street

Arnfield (1990) studied the solar access index of street canyon in the form of H/W in variable value with E-W and N-S street orientations. They are the basic street form pattern and morphological indicators. After that, Ali-Toudert (2006) used these two basic indicators to set up the systematic case studied with H/W=0.5, 1, 2, 4, and orientation= E-W, N-S, NE-SW, NW-SE. There are three typical street form patterns that presented by Shashua-Bar (2006): separated form, continuous form and colonnaded form (Fig.2). He then introduced the "spacing ratio" (buildings' distance parallel to street/building length parallel to street orientation) to quantify the separated form.

Many studies that deal with urban wind effects are also using aspect ratio as the main canopy layer morphological indicator. Oke's basic patterns, highlighting three main situations (isolated roughness, wake interference and skimming flow), is an initiatory example (Oke 1987).

2.2.4 Urban Block/Urban District

In our research, we take the grid aligned arrangement (Panão 2008) as the basic form pattern. Although the morphological indicators presented by Panão are not exhaustive (Table 1), he combines variable values of each indicator to explore the optimum urban building efficiency potential. The study usually focuses on the exploration of horizontal arrangement. Fu (2002) concluded that the residential blocks in general follow five patterns: 1) Parallel columns and rows, 2) staggered rows, 3) staggered columns, 4) oblique rows, 5) surrounding-style and free-style (Fig.3). It is a simplified method to represent a diffuse urban morphology with sraight elements.

One parameter of direct relevance to the UHI phenomenon is albedo of an urban surface. Urban surface albedo is evaluated by the ratio of reflected and incident solar energies. The greater the albedo, the smaller the solar energy stored by the urban surface. The albedo of a city or a district (scale more pertinent at design process) depends on the surface arrangements (e.g. density, orientation, homogeneity, etc.), on the materials used for roofs, paving, coatings, etc., and on the solar position (e.g. site latitude, date and hour). The prediction of the urban energy budget and mesoscale climate involves the study of radiative exchanges within the urban canopy (Miguet 1996). Because these calculations cannot be carried in detail at mesoscale, taking into account real materials and urban forms data, the equivalent surface albedo is used in mesoscale models. This is the main application of the urban surface albedo. However, it is difficult to use this kind of model to calculate albedo of real urban fabrics that are not like checked frames. Starting from prior results obtained (Groleau 2003), this study proposes to calculate albedo for every kind of urban form, including street, single building, and urban block.

FIGURES 1, 2 and 3

Figure 1. RSB, Slab and Pavilion-Court
Source: Ratti, 2003

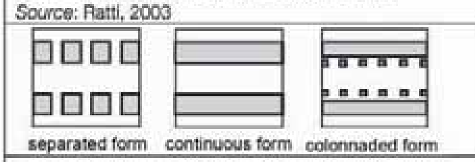


Figure 2. Three Archetype Street Forms
Source: Shashua-Bar 2006

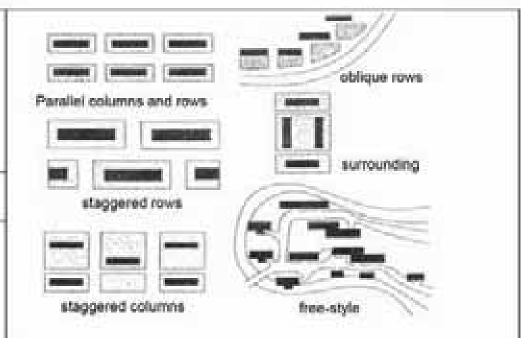


Figure 3. The General Five Block Form Patterns
Source: Fu 2002

3.1 Albedo Calculation: Application to Lyon Confluence

3.1.1 Method

We study surface albedo for different urban blocks in the case of a real urban project that takes place in France: the Lyon Confluence project. After having grouped the radiative characteristics of materials used in this project, we have performed simulations with SOLENE. This simulation tool is able to compute a comprehensive solar and thermoradiative balance of the urban surfaces, thanks to detailed sky vault model and radiosity algorithm (Miguet et al. 1996). Post-processing facilities allow users to analyze accurately the physical variables and fluxes. The first stage relies on 3D modelling of the district as a set of polygonal planar facets of the external surfaces constituting the urban site: roofs, facades, courtyards and streets. A triangular mesh is applied to these facets and calculations take place at the center of each mesh element. The second stage is to assign radiative properties to surfaces.

The first calculation stage, based on geometric procedures, determines the visibility between mesh elements or between a mesh element and a sun location or a sky patch of the geodesic sky model, considering masks. It results in form factors. The second calculation stage examines the solar energy received by each mesh element. The sun and sky irradiation are computed separately; the direct component is evaluated over time (for each sunlit element); and the sky contribution is calculated according to a type of sky (clear, overcast or other) and location of the sun at the considered time. The time-dependent global solar energy received on each mesh element is the first result to be used.

Then, the inter-reflections between surfaces are calculated by a radiosity method that leads to knowledge of net flux received by each facet and the parts that are absorbed or reflected.

At the end, we sum the fluxes absorbed by all the surfaces and the fluxes received directly (not including flux received after reflection) and the albedo is:

$$\rho = \frac{\Phi_S(absorbed)}{\Phi_S(incoming)} \qquad \text{(eq. 1)}$$

Absorbed and global incident fluxes are calculated for three different days: the winter and summer solstices and the equinox so that we can measure the impact of solar azimuth on the albedo.

3.1.2 Results

We studied different blocks of the first stage of the Lyon Confluence project. They are compared to an existing district the « cité jardin » (Fig. 4). In table 2, the characteristics of the blocks and the simulation results have been grouped.

The analysis of results shows that:

- In summer, the horizontal surfaces, including roofs participate fully in the reflection of sunlight. According to materials, there are keys to decrease the UHI effect.
- In order to better exploit the benefits of the UHI effect during the winter period and in particular in reducing energy consumption, it is advisable to use low reflective coatings for the facades of buildings.
- Albedo impact has to be considered carefully when photovoltaic arrays are used. In these cases, heat is not stored in the materials but converted into electricity, so the low albedo property does not really participate in the UHI causes.

A limitation of these results is that the specular reflection of metallic materials could not be taken into account. However, attention must be paid to this high albedo surface because they reflect energy to ground surfaces which are often made with low albedo materials.

FIGURE 4
Aerial view of Lyon Confluence District: Location of the Studied Blocks

Source: www.Lyon-confluence.fr http://photos.pagesjaunes.fr.

TABLE 2
Building Envelope Materials, Computation Results for Incident and Absorbed Solar Energy and Albedo of the Different Blocks

Blocks	Materials Number of concerned Buildings / Façade Materials (Mean Albedo) / Roof Materials (mean albedo)	Simulation date	Global Energy incident (KWh)	Solar Energy Absorbed (KWh)	Albedo
A North	3 / Glazing + metallic frame (0.16) / Photovoltaic arrays (0.05) 1 / concrete + glazing (0.26) / Green roof (0.33)	21-6	1834	1570	**0.14**
		21-3	1192	1024	**0.14**
		21-12	446	380	**0.15**
A South	2 / Concrete + glazing (0.22) / Green roof (0.33)	21-6	1947	1341	**0.22**
		21-3	1259	922	**0.19**
		21-12	475	374	**0.19**
B North	2 / Aluminum + glazing (0/69) / Green roof (0.33) 2 / Aluminum + glazing (0.67) / Photovoltaic arrays (0.05) 1 / Polycarbonate + glazing, (0.18) / Photovoltaic arrays (0.05) 1 / Stainless-steel + glazing (0.67) / photovoltaic arrays (0.05) 1 / Stainless-steel + glazing (0.81) / photovoltaic arrays (0.05) 1 / Concrete + glazing (0.24); Green Roof (0.33)	21-6	3563	2574	**0.27**
		21-3	2083	1501	**0.28**
		21-12	562	389	**0.30**
B South	1 / Stainless-steel + glazing (0.77) / Green Roof (0.33) 2 / Aluminum + glazing (0.67) / Green roof (0.33) 1 / Copper + wood + glazing (0.65) / Green roof (0.33) 1 / Copper + wood + glazing (0.65) / Photovoltaic arrays (0.05) 1 / Stainless-steel + glazing (0.75) / Photovoltaic arrays (0.05)	21-6	2694	1675	**0.37**
		21-3	1785	1011	**0.43**
		21-12	668	355	**0.50**
C	Part 1 / Wood + glazing (0.24) / Wood (0.4) Part 2 & 4 / Concrete + glazing (0.22) / Concrete (0.22) Part 3 / Stainless steal + glazing (0.45) / Stainless steal (0.95) Part 5 / Glass + glazing (0.22) / Glass (0.35)	21-6	4589	3561	**0.22**
		21-3	2822	2181	**0.23**
		21-12	871	671	**0.23**
Lyon confluence	A + B + C	21-6	11101	8656	**0.22**
		21-3	6202	4713	**0.24**
		21-12	2001	1524	**0.24**
Cité Jardin	6 / Concrete + glazing (0.35) / Asphalt (0.2)	21-6	6356	4943	**0.22**
		21-3	3770	2914	**0.24**
		21-12	1146	871	**0.26**

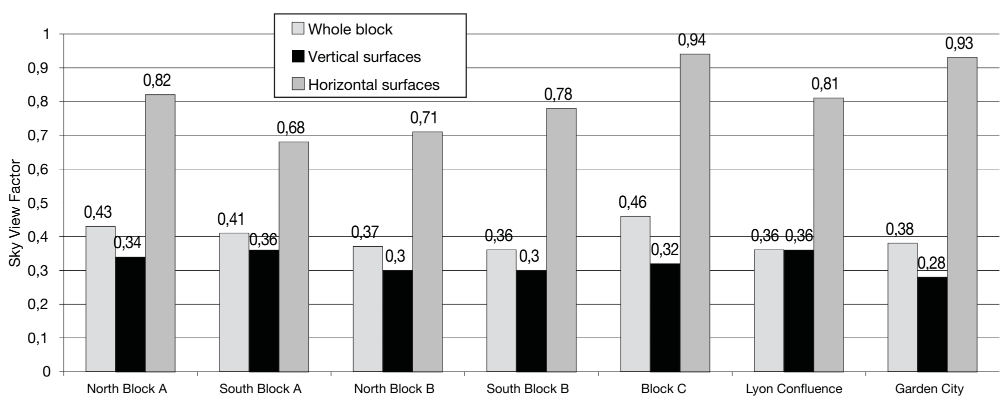
3.2 Albedo Indicator

For these urban blocks, several morphology parameters have been evaluated and correlations examined between them and calculated albedos. The most interesting correlated parameter is the sky view factor (SVF) that corresponds to the percentage (0% to 100%) of the sky vault surface visible from a point in the urban scene. It helps to identify the preferred exchange areas between the considered surfaces and the sky. This indicator is evaluated for each facet of the meshing and a weighted value is calculated for each block. We conducted the analysis separately for horizontal and vertical surfaces.

The histogram analysis (Fig. 5) shows that the horizontal surfaces and particularly roofs have a large SVF. A geometry that presents a large ratio of horizontal surface, including a large proportion of roof shows quite large SVF. We also remark that the vertical surfaces have almost similar SVF than the whole blocks, except for A north and C blocks. This is probably due to the size of their roofs compared to other blocks. Therefore we conclude that the vertical geometry ratio greatly affects the SVF: the greater this ratio, the lower the SVF is.

SVF is a relevant indicator because if we consider a diffuse radiative behavior for any urban facet, the flux reflected out from the city (to the sky) is directly dependent of it's SVF.

FIGURE 5
Mean Sky View Factor of Each Studied Block



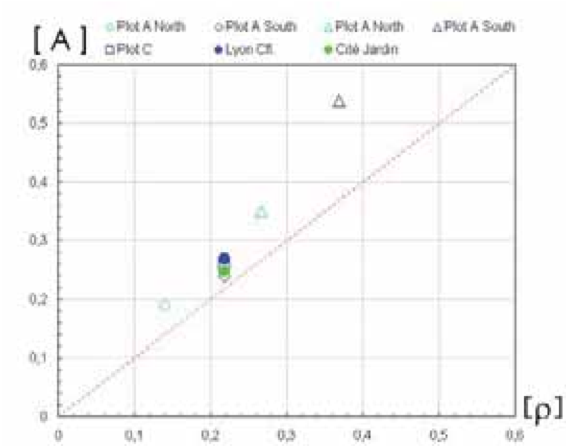
The initial objective was to propose a simple indicator estimate the radiative contribution of a district (real or at design stage) to the UHI effect. Contrary to the strict computation of the albedo that involves important time cost and physical models (sky irradiance model, radiosity algorithm for urban interreflexions), the indicator computation has to be straightforward in order to be dedicated to retroactive decision process at the early stage of projects. The results of the crossing analysis between the surface albedo, geometry and morphology indicators showed that the factors that most impact the value of the district albedo were the average reflection coefficient of the urban fabric and the SVF. We defined the "Albedo index" denoted A, is defined as follows:

$$A = \frac{\sum_{i=1}^{nbFacets} \rho_i S_i SVF_i}{\sum_{i=1}^{nbFacets} S_i} \qquad \text{(eq. 2)}$$

with ρ_i, SVF_i and S_i, the albedo, SVF and area of the facet number i, respectively.

In Fig. 6, we have represented for each part of the district both calculated district albedo ($\rho_{district}$) and the albedo index (A). We can see that the indicator reflects the general trend in the albedo, although there is a little bit of bias. The indicator that we propose widens the role of solar material characteristics and the urban form in the evaluation of the phenomenon of the UHI. Nonetheless it will operate as a kind of pre-diagnosis of the quality of the elements of urban form that will be complemented by computer simulations of physical phenomenon.

FIGURE 6
Albedo Index (A) versus Theoretical Albedo Computation (ρ) on x-Axis



This study can be used to increase the awareness of urban planners, designers and decision makers on the importance of the choice of coating, paving and roof materials not only for their aesthetics, but also their function, specifically in terms of their effect on local climate and indirectly on energy consumption of buildings. It is worth noting this study could be enhanced by site experiments, in addition to computer simulations, especially as albedo indicator values are all quite far from the real albedo values.

4. MICROCLIMATE — ENERGY CONSUMPTION SIMULATION

The previous approach points out the role the urban surface based on a single phenomenon: the solar radiation. This is important to measure the impact of materials on urban form and on the UHI, but at lower scales, it is necessary to evaluate the impact of local urban design on outdoor thermal comfort and buildings' energy consumption. Currently, there is a lack of efficient tool appropriate to the designer needs. The approach is to develop a research tool that allows to test configurations and learning about the physical phenomenon taking place in an urban space and their impact on building energy consumption.

4.1 Method

Our tool has to take into account the different energy transfer processes:

- evapotranspiration from the vegetation and soil;
- solar radiation from sun and sky vault and reflection between surfaces;
- infra-red exchanges between urban surfaces and sky;
- convective transfer between surfaces and air with an explicit computation of wind flow;
- conductive transfer of heat stored in buildings and ground.

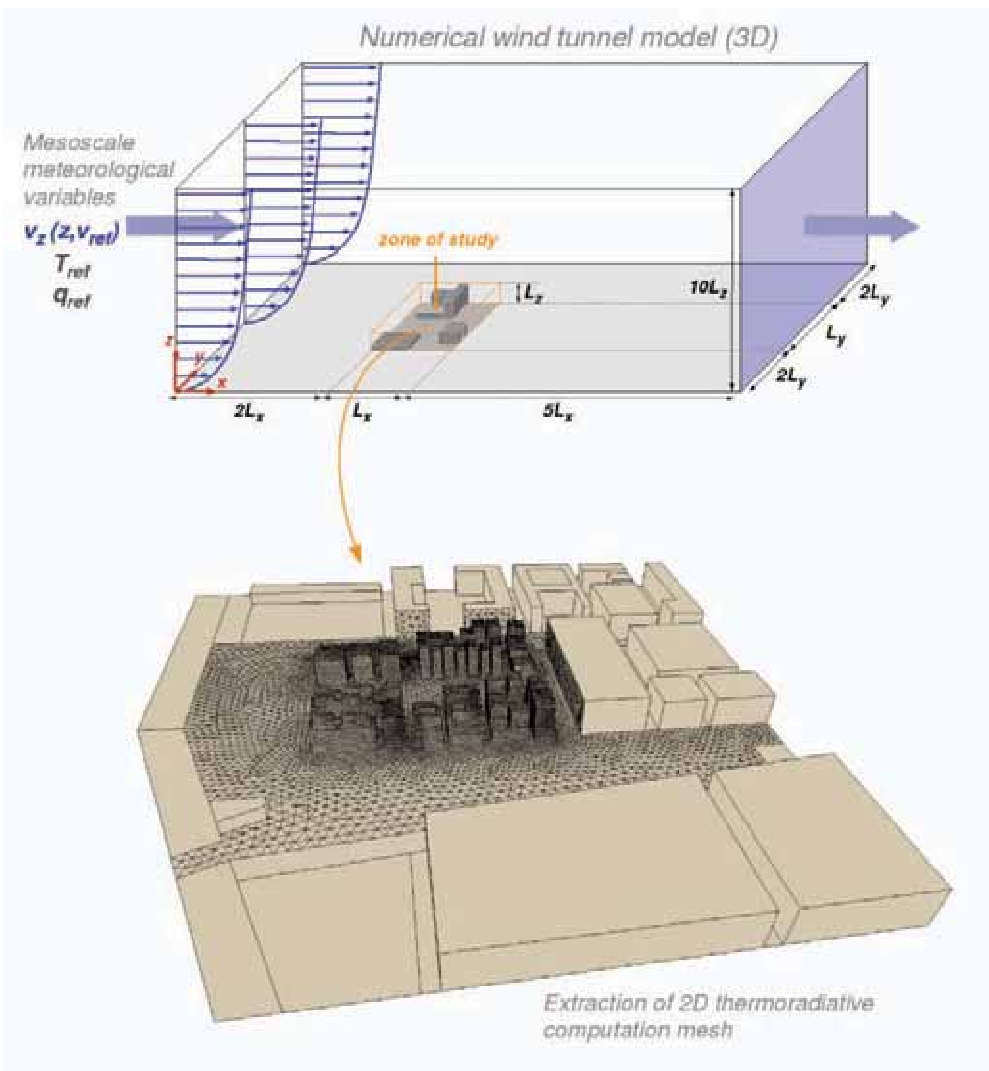
It relies on a dynamic computation integrating three coupled modules:

- An industrial computation fluid dynamics (CFD) tool, FLUENT, customized by specific functions, allows the model to obtain precisely the outdoor aerodynamic, thermal and hydrous conditions near the building;
- The thermoradiative model, named SOLENE (see Part 3.1.1.), which computes the solar and infra red balance and gives the temperature of the surfaces according to the urban layout and the material characteristics; and

- A thermal model of the building specially developed for this study and integrated to, which is able to compute indoor thermal conditions according to the physical environment given by the two previous models.

The first two modules evaluate the time-dependant spatial distribution of the climatic variables according to a fine 3D mesh (Fig.7), while the third module computes the mean thermal variables of the different building floors.

FIGURE 7
Simulation 3D Model and Surface Meshing Generation

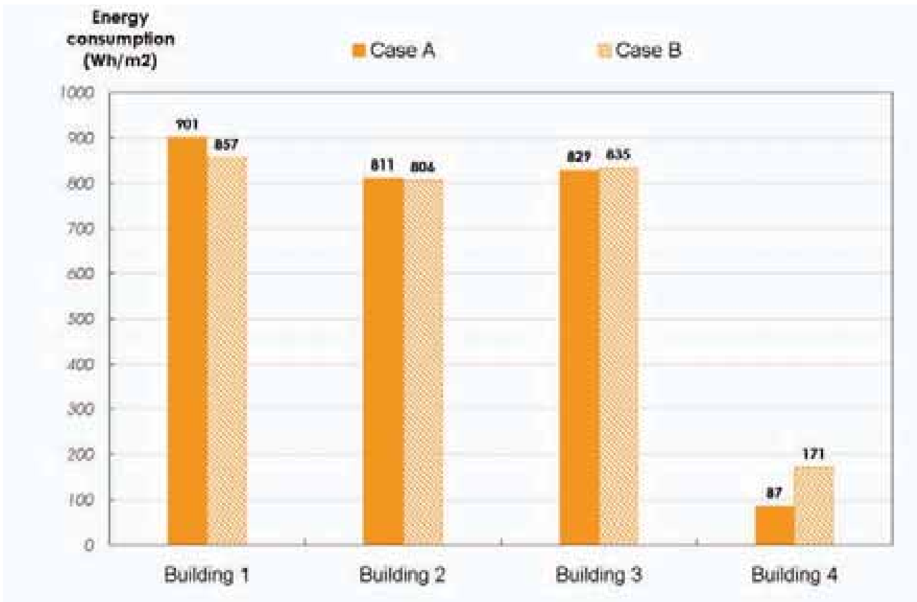


4.2 Results

An application in the real urban context of Lyon Confluence presented above was carried out aiming to compare two kinds of urban design: a mineralized one (Case A) and natural one (Case B) (Fig. 8). Four target office buildings have been studied. Geometry, occupancy and building envelope materials were the same, but compactness, glazing and orientation were different. Note that shading devices are integrated for building 1 and 2.

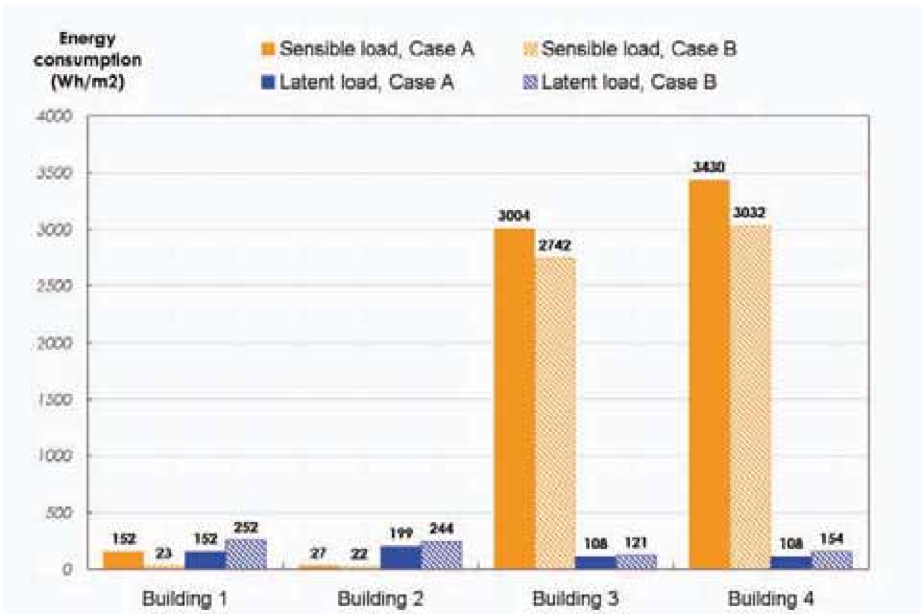
FIGURE 8
The Two Studied Surroundings, Mineralized (Case A) and Green (Case B)

FIGURE 9
Energy Consumption for Different Kind of Building Respecting French Thermal Standards for a Winter Week and According to the Two Design Cases



The winter results show that buildings 1, 2 and 3 have almost the same energy consumption during the simulation week. Only building 4, which is more exposed to the solar radiation, does not have the same heating needs. The vegetated design of outdoor space do not strongly modify the consumptions except for building 4, where there remain a residual mask effect due to the branches (deciduous trees), taken equivalent to 70% transmissivity of the virtual modeled 3D tree crown.

FIGURE 10
Energy Consumption for Different Kind of Building Respecting French Thermal Standards for a Summer Week and According to the Two Design Cases



The summer results show that buildings 1 and 2 confirmed the advantage of integrated shading to save cooling needs. The impact of the green design can be observed for building 3 and 4, for which the savings reach respectively 8.7% and 11.6%.

5. CONCLUSION AND FUTURE WORK

We have shown how urban forms can be classified and how proposed morphology indicators can help to characterize them with regard to their energy performance.

The use of morphology indicators needs to be validated. In this paper, we have illustrated how a new indicator, the albedo indicator, is built starting from urban form considerations. We have thus applied to a real project in terms of the stages of albedo indicator validation. For this purpose, we have compared the values of the albedo indicator to the values obtained when proceeding to complete albedo calculation using computer intensive calculations. The results show, in the studied case a bias between the two coefficients but a similar general trend.

So the proposed indicator can be used as a first approach for contribution to a project regarding UHI by evaluating its surface albedo and comparing different strategies of materials and buildings' forms and arrangements.

However, for fine material arrangement decisions, we propose to use the complete albedo calculation because in the indicator, the effect of geometry is incomplete. Indeed, the effect of geometry is taken into account by the SVF that permits to render the exchanges that the surfaces are liable to have with the sky, but not their orientation with regard to the sun course. We will soon propose a new simplified indicator better adapted for this kind of studies.

We have also presented a set of tools developed that allows for examination of thermal phenomena that occur in a complex urban scene and analyzing of the effect of different urban designs on microclimate (comfort purposes) and on buildings' energy consumption. We are able to simulate an urban scene taking into account the presence of grass, trees, and water ponds, and obtain the wind velocity, air temperature and humidity, surfaces temperatures and evaluate the energy balance of a building. Results obtained with this tool have been presented. Their consistency has been verified, but results still need to be validated with regard to experimental data, which will be the next stage of the work.

Tools being almost mature, our aim is to use them in a methodical way in order to produce guidelines for designers. The parameters concerned with urban design that affect microclimate and energy consumption are numerous: urban forms, surface materials, vegetation and water presence, and buildings' use. Moreover, as we pointed out in the introduction, their effect on different phenomena can be antagonist. The first step is to analyze, for one particular urban project, the effect of form, studying the different classes of the typology and varying the morphology indicators, as illustrated in this paper. This is followed by study of the surface design strategies, for buildings' envelope and for public space between buildings.

References

Akbari, H., Pomerantz M., and H. Taha. 2001. "Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas." *Solar Energy* 70 (3): 295–310.

Ali-Toudert, F., and H. Mayer. 2006. "Numerical Study on the Effects of Aspect Ratio and Orientation of an Urban Street Canyon on Outdoor Thermal Comfort in Hot and Dry Climate." *Building and Environment* 41: 94–108.

Arnfield, A. J. 1990. "Street Design and Urban Canyon Solar Access." *Energy and Buildings* 14: 117–131.

Brown, G. Z., and M.W. Dekay. 2001. *Sun, Wind and Light: Architectural Design Strategies*. New-York: John Wiley and Sons.

Chimklai, P., Hagishima A., and J. Tanimoto. 2004. "A Computer System to Support Albedo Calculation in Urban Areas." *Building and Environment* 39 (10): 1213-–21.

Fu, S. X. et al. 2002. *Building Energy Efficiency Technology in Hot-Summer and Cold Winter Area*. Beijing: Architecture Industry Press of China.

Givoni, B. 1989. *Urban Design in Different Climates*. World Meteorological Organisation, WMO/TD No.346.

Groleau, D., Fragnaud F., and J.M Rosant. 2003. "Simulation of the Radiative Behavior of an Urban Quarter of Marseille with the Solene Model." Proceedings of the "5th International Conference on Urban Climate, ICUC," Lodz, Poland.

Miguet, F., Groleau, D., and C. Marenne. 1996. "A Combined Sunlight and Skylight Tool for Microclimatic Analysis in Urban Architectures." Proceedings of the "4th European Conference on Solar Energy in Architecture and Urban Planning," Berlin, 338–45.

Mills, G. 1999. "Urban Climatology and Urban Design". Proceedings of the "15th ICB & ICUC," Sydney, Australia, November 8–12.

Oke, T. R. 1984. "Towards A Prescription for the Greater Use of Climatic Principles in Settlement Planning." *Energy Buildings* 7: 1–10.

Oke, T.R. 1987. *Boundary layer climates.* 2nd ed. Methuen, London and New York.

Panão, M. J. O., Goncalves H. J., and P.M. Ferrão. 2008. "Optimization of the Urban Building Efficiency Potential for Mid-Latitude Climates using a Genetic Algorithm Approach." *Renewable Energy* 33: 887–96.

Ratti, C., Raydan D., and K. Steemers. 2003. "Building Form and Environmental Performance: Archetypes, Analysis and an Arid Climate." *Energy and Buildings* 35: 49–59.

Santamouris, M. 2001. *Energy and Climate in the Urban Built Environment*. London: James and James.

Santamouris, M., Papanikolaou N., Livada I., Koronakis I., Georgakis C., Argiriou A., and D.N. Assimakopoulos. 2001. "The Impact of Urban Climate on the Energy Consumption of Buildings." *Solar Energy* 70 (3): 201–16.

Shashua-Bar, L., Hoffman M.E., and Y. Tzamir. 2006. "Integrated Thermal Effects of Generic Built Forms and Vegetation on the Ucl Microclimate." *Building and Environment* 41: 343–54.

CHAPTER 6

Framework for City Climate Risk Assessment

Shagun Mehrotra,* Claudia E. Natenzon, Ademola Omojola, Regina Folorunsho, Joseph Gilbride, Cynthia Rosenzweig

Abstract

Estimation of spatially and temporally disaggregated climate risks is a critical prerequisite for the assessment of effective and efficient adaptation and mitigation climate change strategies and policies in complex urban areas. This interdisciplinary research reviews current literature and practices, identifies knowledge gaps, and defines future research directions for creating a risk-based climate change adaptation framework for climate and cities programs. The focus is on cities in developing and emerging economies. The framework developed by Mehrotra unpacks risk into three vectors—hazards, vulnerabilities, and adaptive capacity. These vectors consist of a combination of physical science, geographical, and socioeconomic elements that can be used by municipal governments to create and carry out climate change action plans. Some of these elements include climate indicators, global climate change scenarios, downscaled regional scenarios, change anticipated in extreme events, qualitative assessment of high-impact and low-probability events, associated vulnerabilities, and the ability and willingness to respond. The gap between existing responses and the flexible mitigation and adaptation pathways needed is also explored. To enhance robustness, the framework components have been developed and tested in several case study cities: Buenos Aires, Delhi, Lagos, and New York. The focus is on articulating differential impacts on poor and non-poor urban residents as well

*Corresponding author: mehrotrs@newschool.edu

as sectorally disaggregating implications for infrastructure and social well-being, including health. Finally, some practical lessons are drawn for successful policies and programs at the city level that aim to reduce systemic climate risks especially for the most vulnerable population. Additionally, a programmatic response is articulated with a four-track approach to risk assessment and crafting of adaptation mechanisms that leverages existing and planned investments in cities so that city governments can respond to climate change effectively, yet efficiently.

1 INTRODUCTION[1]

Local governments are beginning to put a greater focus on adapting their cities to the inevitable effects of climate change. This is a result of the lag between when reductions in greenhouse gas emissions will occur and the time it takes for those effects to be felt in the climate system. Overall, climate change and increased climate variability will alter the environmental baselines of urban locales, such as the temperature regimes and precipitation patterns. Shifts in climate and increased frequency of extreme events have direct impacts on water availability and quality, flooding and drought periodicity, and water demand amongst a host of conditions. These dynamic changes will affect system processes within multiple sectors in cities interactively, increasing the uncertainty under which urban managers and decision-makers must operate.

In response, this paper focuses on developing a new framework for urban risk assessment, thus laying emphasis on how cities are affected by climate change as opposed to the impact of cities on climate change through greenhouse gas emissions. This paper focuses on adaptation aspects of climate change and not mitigation, particularly because adaptation has been neglected until recently both in developed and developing-country cities alike (IPCC 2007a). Further, adaptation remains a critical concern in most developing country cities where *per capita* emissions are already at relatively low levels[2]. The purpose of this paper is to fill this critical gap by crafting a risk assessment framework for cities that synthesizes existing local information, testing the framework on four geographically-diverse large cities, and identifying a programmatic response to the development of climate change risk assessment and adaptation planning pathways, which are effective, efficient, and necessary responses to climate change at the city-level.

---

[1]The ideas outlined in this paper have been further developed in Climate Risk, Disasters, and Cities Mehrotra, et al., 2011) as well as an academic journal (Mehrotra, forthcomming).

[2]Large cities in seventeen major economies account for most GHG emissions: Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, South Africa, the United Kingdom, and the United States.

Understanding how cities craft institutional mechanisms to respond is an important complement to this risk assessment framework. This has been briefly explored where relevant, for detailed case studies on Quito and Durban (see Carmin and Roberts 2009) and the eight-stage risk, uncertainty and decision-making framework developed by UK Climate Impacts Programme (2009), which aims 'to help decision-makers identify and manage their climate risks in the face of uncertainty.'

For the purposes of policymakers, this framework looks at the projected impacts of climate change through the end of the twenty-first century. Climate projections for the twenty-second century have even larger uncertainties and lie beyond the likely planning horizons for most urban development and thus are not addressed here. Despite the uneven availability of data for developing-country cities, research done for this paper suggests that time-series of observed climate parameters are readily available for hundreds of cities and that gaps in data do not limit use of climate models for projections. Further, we find that relatively straightforward downscaling of global climate model simulations provides ample information for assessing urban-scale vulnerability and risks, at least in initial stages. Finally, data on city characteristics through the global urban observatory of UN-Habitat are also available. By complementing these metrics with city-specific analysis by local experts and existing studies, we find that it is feasible to conduct substantive climate change vulnerability and risk assessments for cities around the world, as demonstrated in this paper.

2 LITERATURE REVIEW

This review articulates the implications of climate risks as they pertain to cities with a focus on differential impacts on the poor and the non-poor as well as on a range of urban sectors—transport, water and sanitation, energy, and health. Highlights from the relevant climate change studies are discussed in the section on case studies. The emphasis is on the enhanced vulnerability of the poor in most future scenarios, and the lack of capacity to mitigate and adapt to short and long-term climate risks is articulated. From the literature review, we identify useful attributes of a climate risk framework, some of which are addressed in the research.

At the global-level, the IPCC Working Group I identified four major aspects of climate change relevant to cities in its synthesis report (IPCC 2007a). First, heat waves are very likely to increase in frequency over most land areas. Second, heavy precipitation events are very likely to increase in frequency over most areas; available data suggest that a significant current increase in heavy rainfall events is already occurring in many regions. The resulting risk poses challenges to urban society, physical infrastructure, and water quantity and quality. Third, the area affected by drought is likely to increase. There is high confidence that many semi-arid areas will suffer a decrease in water resources due to climate change. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, including food production, water supply, energy supply, and health. Fourth, it is likely that intense tropical cyclone activity will increase. It is also likely that there will be an increased incidence of extreme high sea level (excluding tsunamis).

Further, the IPCC (2007b) Working Group II lays emphasis on conceptual issues regarding urban climate change with a focus on economic and social sectors in Chapter 7 on Industry, Settlements, and Society. The review identifies four key findings with *very high* or *high* confidence. First, climate change effects can amplify the risks that cities face from non-climate stresses. These non-climate stresses include large slum populations that live in low-quality housing lacking access to basic social services; city-wide lack of access to effective and efficient physical infrastructure; often-poor quality of urban air, water, and waste disposal systems; lack of land-use planning and other urban governance systems, among others. Further, the climate change associated risks for cities stem primarily from extreme events—implying that cities need to assess risk for droughts, floods, storms, and heat waves, in order to plan and implement adaptation strategies. However, gradual changes such as rise in mean temperature do affect cities in at least two significant ways: by increasing the frequency and intensity of extreme events and burdening the existing infrastructure.

Second, vulnerability of a city depends on 'geographic, sectoral, and social' attributes. For instance, the risk to a city's infrastructure, firms, and households is greater in coastal and other flood-prone areas or in economic sectors that are vulnerable to climate variability, like tourism. Likewise, in developing countries, an increasing proportion of the urban population and local economies are at risk as cities are rapidly growing on susceptible land. Poor households in cities are particularly vulnerable because they tend to occupy 'high-risk areas' (such as riverbeds, and flood plains), their communities lack resources to adapt, and they rely extensively 'on local climate-sensitive resources such as water and food supplies.'

Third, disaster management—prevention, preparedness, and response—are intrinsically related to climate change management because in cities where climate-induced extreme events become more frequent and intense, the costs can range from a small fraction of the regional economy in large regions with big economies to as much as a quarter in small regions with small economies. Further, through organic linkages, the impacts from climate change can spread across urban regions and sectors, posing systemic risks.

Fourth, cities have a certain degree of resilience to climate change and embody adaptive capacities, although within limits. And while adaptation responses for cities are locally grounded, regional, national, and global linkages can enhance adaptive capacities through resource transfers and knowledge exchange.

The impacts of climate change will vary across cities as well as among households and sectors within cities. In this regard, scholars and practitioners concerned with urban development argue for the need to focus on the poor, as they are more vulnerable due to their lack of access to infrastructure and their relative inability to hedge against risks. UN-Habitat (2008a, 2008b), the United Nations' agency for human settlements, as well as the International Institute for Environment and Development (Satterthwaite et al. 2007), among others, have articulated the need to focus attention on developing country cities due to several interrelated factors. Half the world's population is urban, and cities, which are the engines of economic growth, are extremely vulnerable to climate change. This is particularly so in developing countries where most coastal mega-cities are located and that are home to rapidly growing population centers (UN-Habitat 2008a). The challenge posed by climate change for African cities is particularly alarming (UN-Habitat 2008b).

Developing country cities face more risks of economic and social catastrophes due to their relative lack of resources to adapt and mitigate. These cities also offer opportunities to address the needs of some of the most vulnerable urban populations of the world—essentially about a billion slum dwellers, a section of the urban population that is projected to grow to two billion by 2020. As poverty has often been primarily associated with rural areas, this population has received relatively less attention. However, there an increasing recognition of the 'urbanization of poverty' (UN-Habitat 2003).

There is a critical need for sectorally-tailored analysis of climate hazards, sector-specific vulnerabilities, and location-specific adaptive capacities, as has been highlighted by the most recent IPCC Working Group III AR4 (2007c) and the World Resource Institute, which focuses on sectorally-disaggregated mitigation strategies (see Baumert et al. 2005; Bradley et al. 2007). OECD, in a literature review on climate impacts on cities also identifies such gaps, concluding, for example, that most analysis on climate impact assessments and cities has neglected non-coastal cities and that uncertainties in assessing the economic impacts need to be incorporated, particularly for developing-country cities where variances are likely to be higher (Hunt and Watkiss 2007; Hallegatte et al. 2008). Further, there is a need for city-specific efforts to graduate from awareness-raising to impact assessments—including costing impacts and identifying co-benefits-and-costs—and adaptation analysis so that 'no-regret adaptation options' can be adopted to increase resilience of cities to climate change. Economic costs of climate change in cities need to 'bracket' for uncertainty and assess both intra-and-inter sectoral and systemic risks to address direct and indirect economic impacts.

Risk frameworks tend to fall broadly into three categories or groups. The first group of risk frameworks stems from the work of climate scientists associated with the IPCC and focuses primarily on climate hazards—variances in mean and extreme climate parameters, collectively referred to as climate hazards. The second group emerges from the work of planners and policymakers, such as those associated with UN-Habitat's *The Cities in Climate Change Initiative* (CCCI) or the World Bank, East Asia Unit's recent analysis summarized in the *Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters*, focus on vulnerabilities—essentially city characteristics that determine the susceptibility of a city to climate change. The third group of risk frameworks focuses on economic analysis of climate impacts, such as the OECD reports (Hunt and Watkiss 2007 and Hallegatte et al. 2008) or the Stern Review on the Economics of Climate Change (Stern 2007). These cost-accounting exercises define risk as the cost of catastrophe weighted by the probability of extreme events.

In sum, the literature points to the pressing need for understanding risks associated with climate change as they pertain to different types of cities—coastal versus non-coastal and developed versus developing; different sectors—physical infrastructure such as energy, transport, water supply, as well as social services such as health and environmental management (and the complex interactions among these sectors); and differential impacts on the poor or the young and old, who are more vulnerable than the rest of the urban population. The goal of this paper is to develop and test a climate change risk framework that captures the complexities resulting from the interactions of these factors, thus filling a critical gap in research as well as practice.

3 FRAMEWORK FOR RISK ASSESSMENT

Climate change assessments have focused at the country-level and therefore lack a city-specific emphasis. Further, many city managers are yet to address climate change in their management strategies largely because city-specific risks remain undefined and more short-term problems such as lack of basic services or aging infrastructure take precedence. However, even when climate risk is identified at the local scale the focus is on climate hazards. Two additional vectors are critical and often neglected in cities—namely vulnerability and adaptive capacity. Vulnerability of a city is determined by a host of internal characteristics of the city. Adaptive capacity is a function of the ability and willingness of the city stakeholders to respond to and prepare for future climate-induced stresses.

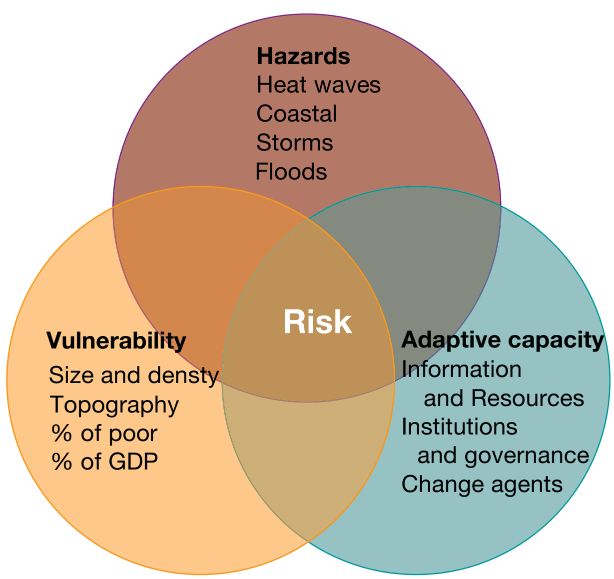
To address this critical gap, the aim of this new framework developed by Mehrotra for urban climate risk assessment is to unpack, or deconstruct risk, into three elements: *hazards*, *vulnerability*, and *adaptive capacity*. Similar frameworks have evolved in disaster risk reduction, however they use different indicators (for instance see Shook 1997). However, these conceptual frameworks owe their roots to the evolution of concepts of development economics from the Rawlsian notions of development (1971) to that of Sen's (1999) capability-based approach, which accounts for both internal constraints and degrees of agency, in addition to constraints due to external conditions (Mehrotra, forthcoming).

The challenge is to translate information from climate science into knowledge that triggers a realistic assessment of the vulnerability of the city and its systems, so as to facilitate the development of pragmatic adaptation strategies. The goal of this Urban Climate Risk Framework is to assist policymakers in assessing and responding to the risks associated with climate change in cities. The specific objectives of the framework are three-fold:

1. Characterize the hazards associated with climate change at the city-level;
2. Identify the most vulnerable segments (people, locations, sectors) of the city; and
3. Assess the city's ability to adapt to anticipated changes in climate.

Risk is defined by Mehrotra as the product of the three vectors: hazards, vulnerability, and adaptive capacity (Figure 1, adapted from Mehrotra 2003; Rosenzweig and Hillel 2008).

FIGURE 1
Framework for Urban Climate Risk Assessment



Source: Adapted from Mehrotra (2003) and Rosenzweig and Hillel (2008)

Hazards: These are defined as the climate-induced stresses on the city and are identified through observed trends and projections derived from global climate models (GCMs) and regional downscaling. Extreme events affected by climate change include heat waves, droughts, inland floods, accelerated sea level rise, and floods for coastal cities. The variables examined to track these hazards are temperature, precipitation, and sea level. In essence, the hazard element of the framework structures the array of climate change information into the key stresses that potentially have the greatest consequence for the specific city under consideration. In this regard, it is critical to draw attention to both the variation in climate means and the change in frequency and intensity of extreme events. The latter offers opportunities for linkages with disaster risk reduction programs and has received perhaps more attention, while the former has critical long-term implications for city infrastructure and development, and tends to receive less attention because the mean changes are gradual.

Vulnerability: These are physical attributes of the city and its socio-economic composition that determine the degree of its susceptibility. The variables affecting vulnerability include flood-proneness (proximity to coast or river), land area, elevation, population density, percentage of poor, and quality of infrastructure. OECD's work on city vulnerability in the context of climate change points to such variables as location, economy, and size as well (Hunt and Watkiss 2007). More detailed indicators such as composition of the poor population—age, gender, labor force composition and the like—need to be taken into consideration when in-depth city vulnerability analysis is conducted, but for the purpose of this study a more restricted set of variables that are readily available for most cities is utilized, essentially to illustrate that such physical and socio-economic characteristics affect a city's risk.

Adaptive Capacity: These are institutional attributes of the city and its actors that determine the degree of its capability to respond to potential climate change impacts. Thus they provide measures of the ability (institutional structure, caliber, resources, information, analysis), and willingness (of actors—local governments, their constituent departments, private sector, civil society—NGOs, academics) to adapt to climate change. Variables that can determine the extent of a city's ability to adapt include the structure and capacity of institutions, presence of adaptation and mitigation programs, and motivation of change agents. Here it is critical to draw a distinction with the term 'resilience[3]' that the IPCC (2001b) Working Group II assessment defined as "amount of change a system can undergo without changing state." In contrast, adaptive capacity does not assume a steady state of a city and its integrated systems; rather it measures the ability and willingness to not only cope but to respond positively to the stresses that climate change imposes.

---

[3]*Coping Range* and *Exposure* are two related concepts that climate change scientists often include within vulnerability that are germane to the framework described here. IPCC (2007) defines coping range as 'variation in climatic stimuli that a system can absorb without producing significant impacts' while exposure is "nature and degree to which a system is exposed to significant climatic variations."

3.1 Measuring Hazards through Climate Change Scenarios

Analysis of hazards specific to a particular city should include observed and projected data on key climate parameters—temperature, precipitation, and sea-level rise, among others. Further, each hazard[4] needs to be analyzed for variance in climate parameter over the short- and long-term and where relevant for frequency as well as intensity of extreme events. Climate change scenarios provide a reasonable understanding of potential future climate conditions (Parsons et al. 2007). It is not expected that a single climate model will project exactly what will happen in the future, but by using a range of climate model simulations along with scenarios incorporating different atmospheric concentrations of greenhouse gases, a range of possible climate outcomes are produced and can be presented as projections that demonstrate the current expert knowledge.

Local climate change information is derived from the scenarios of greenhouse gas emissions and global climate model simulations described above. Quantitative projections are made for key climate variables such as the change in mean temperature that reflect a model-based range of values for the model grid boxes covering Buenos Aires, Delhi, Lagos, and New York City. Further, there is need for a nuanced understanding of the complex interactions between hazards and the city. This is because the city can be both a producer as well as a receiver of these hazards. For instance, New York City alone contributes about 0.25 percent of global greenhouse gas emissions (The City of New York 2007). On the other hand, an increase in sea level also increases the city's susceptibility to flooding. Furthermore, while both the urban heat island and global warming increase the ambient temperature of the city, one is internally generated while the other is externally induced.

3.2 Measuring Vulnerability

Vulnerability is defined as the extent to which a city is predisposed to "adverse effects of *climate change*, including *climate variability* and extremes" (IPCC 2007d). However, unlike the IPCC definition of vulnerability that includes adaptive capacity, we decouple the two and address them individually, considering vulnerability to be determined by the physical and underlying social conditions of the city while adaptive capacity is determined predominantly by the change agents. Vulnerability is a function of a host of city characteristics,

---

[4]*Defining Climate Risk Factors*: Climate change (or climate variability) affects hazard, vulnerability and adaptive capacity through a variety of direct and indirect relationships, although the most direct, well-understood effect is on hazard. Climate change manifests itself in changing temperatures and changing temporal and spatial atmospheric circulation patterns. Increasing temperatures are very likely to result in continuing sea level rise, which increases the likelihood of flooding of coastal regions. Rising sea levels also increase storm surge, wave damage, and coastal erosion—particularly significant effects considering that population and other assets are becoming ever-more concentrated in coastal regions. Changes in rainfall will mean increased flooding and water shortages, in some cases for the same region. Changing patterns of tropical storms are likely to bring higher winds and more intense rainfall affecting buildings and infrastructure not designed for these impacts.

including but not limited to the location of a city, particularly its proximity to the sea, topography, or any other physical attributes of the landscape or physical geography that make the city susceptible to climate variations.

Social factors that determine the degree of vulnerability of a city include its population size and composition, density, size, quality of infrastructure, type and quality of its built environment and its regulation, land use, governance structure, and the like. A critical factor determining the vulnerability of the poor, as opposed to the non-poor population of the city, is the percentage of the population living in slums. These are households that lack access to one or more of the following: improved water supply, improved sanitation, sufficient living-space, structurally sound dwellings, and security of tenure (UN-Habitat 2003). The contrast between the formally planned part of the city and the slums is stark and is a key determinant of the differential vulnerability of the poor as opposed to the non-poor (UN-Habitat 2008a).

3.3 Measuring Adaptive Capacity

Adaptive capacity is the ability and willingness of the city's key stakeholders to cope with the adverse impacts of climate change, and depends on the awareness, capacity, and willingness of the change agents. A quick measure of institutional awareness is the presence of a comprehensive analysis of climate risks for the city and corresponding adaptation and mitigation initiatives. Capacity here refers to the quality of institutions at various levels of governments—local, regional, and national—and within local government, across various departments. Further, the capacity of the private sector, non-governmental organizations, and community groups to respond also matters. Finally, the willingness to act is of essence. In this regard, identifying in substantial detail the leading actors for climate response—government, private sector, and civil society—and mapping their initiatives is essential for estimating the adaptive capacity of a city.

3.4 Data Sources and Uncertainties

The indicators selected (see Table 1) are based on comparable data compiled in readily accessible databases like the United Nations Population Statistics, UN-Habitat's Global Urban Observatory databases, the World Development Indicators of the World Bank, and other international data sets. For a comprehensive review of available and planned urban indicators see Hoornweg et al. (2007).

TABLE 1
Three Vectors of Urban Climate Risk

Hazards	Vulnerability	Adaptive Capacity
1. Temperature 2. Precipitation 3. Sea-level 4. Tropical cyclone 5. Drought 6. Heat waves	1. Population 2. Density 3. Percent of slum population 4. Percent of urban area susceptible to flooding	*Institutions and Governance* 1. Urban governance (corruption index ranking for city) 2. City leadership is willing to address climate change *Information and Resources* 3. Comprehensive analysis of climate risks for the city 4. Administrative unit assigned to address climate change

Source: Mehrotra

The aim is to create straightforward indicators and communication tools that will provide timely and ongoing assessments of climate risks to inform the adoption of appropriate adaptation programs and policies in urban areas. An uncertainty rating similar to that employed by the IPCC (IPCC 2007a) has been utilized for the climate projections, and is based on the correspondence between the observations and model projections (either existing or modified), the agreement among models, and expert judgment. However, as the framework is applied to cities, higher-quality locally available data will often allow for further analysis as illustrated through the case study cities. While sensitivity analysis to capture uncertainty is a useful concept to apply to vulnerability and adaptive capacity indicators as well, it is beyond the scope of this paper.

4 METHODOLOGY: FRAMEWORK APPLIED TO FOUR CITIES

To test the framework developed by Mehrotra, the co-authors conducted case studies for the metropolitan areas of several cities[5]—Buenos Aires, Delhi, Lagos, and New York. The primary criterion for selecting these cities is that all four have leadership that is committed to addressing the issue of climate change[6] and thus the risk analysis is expected to inform policymakers as well as yield response through the creation of programmatic responses needed to

[5]The unit of analysis for this paper is the city. The city is defined as the urban agglomeration that constitutes the broader metropolitan area and has overlapping jurisdictions. While every effort has been made to maintain consistency across the four cities, due to varying legal traditions and related local administrative differences the units are not strictly identical, but are broadly comparable.

[6]All cities are members of the C40 Large Cities, Climate Leadership Group, http://www.c40cities.org/ and all co-authors are members of the Urban Climate Change Research Network http://www.uccrn.org

create flexible climate adaptation pathways. Further, these cities are located on four different continents and have a range of socioeconomic conditions and vulnerability to climate hazards. As these are all megacities and important national urban centers in their respective countries, not only do they constitute a significant share of the national GDP but also help to shape the direction of national urban development policies. See Table 2 for demographic parameters for the case study cities.

TABLE 2
Demographics for the Case Study Cities (Metropolitan Area)

Metropolitan Area	Population	Area	Population Density	Slum Population As A Percentage Of National Urban Population
Buenos Aires	12.0 million	3,833 km^2	3,131 people per km^2	26.2 percent
Lagos	7.9 million	1,000 km^2	7,941 people per km^2	65.8 percent
New Delhi	12.9 million	9,745 km^2	1,324 people per km^2	34.8 percent
New York	8.2 million	790 km^2	10,380 people per km^2	N.A.

Sources: Authors' compilation from city, state, and national statistics and census bureaus of Argentina, India, Nigeria, and United States; slum data from UN Habitat 2008.

Most aspects of the risk framework articulated in this paper are equally applicable to smaller cities, as in many cases time-series data on climate parameters are available. Smaller cities may have fewer resources to apply to the development of climate risk responses and thus may have additional needs for national and international guidance and support. However, the diverse urban conditions in the case study cities allow for some generalized lessons to be drawn regarding effective and efficient urban responses to climate change. The combination of city cases allows for a comparison among developing countries as well as contrasts between developed and developing country cities, their challenges, and responses.

For each city, available knowledge is analyzed for various aspects of climate risks, including uncertainty.

Background information from the case study cities has been evaluated and selected variables have been assigned to the framework components. The case studies allow for preliminary tests of the transferability of the climate risk framework to a variety of cities and to explore what 'climate services' of data analysis, access, and processing need to be provided at the international level.

To provide concrete examples of how climate risk information can be communicated, current trends in key climate variables (including temperature, precipitation, and the incidence of extreme events) for each of the case study cities have been determined, and recent IPCC 2007 projections (up to sixteen models and three emissions scenarios) have been used to create city-focused downscaled climate model projections. The degree to which these models are able to replicate observed climate and climate trends in the past several decades is described. We also explore discrepancies, if any, between the identified risks and vulnerabilities and the current responses of cities to climate-related hazards. This addresses the important question of real-versus-perceived needs. Finally, how such information contributes to urban vulnerability assessments, quantification of the range of potential impacts, and formulation of practical, user-relevant adaptation strategies is explored.

4.1 Buenos Aires

Buenos Aires is the third largest city in Latin America, and is the political and financial capital of Argentina. The city is composed of several sub-jurisdictions that were added as the city expanded since its inception in the fifteenth century as a Spanish port. The Greater Buenos Aires Agglomeration (AGBA) is the largest in Argentina, with over 12 million inhabitants (National Population Census 2001), with 77 percent of the population living in the surrounding provincial boroughs, and 23 percent in the central urban core of Buenos Aires City (Instituto Nacional de Estadística y Censos [INDEC] 2003). Buenos Aires City (CABA) is administered by an autonomous government elected directly by its citizens. With less than 10 percent of the Argentinean population, the CABA produces around 24 percent of the GDP. The Geographic Gross Product of the city in 2006 was about US $50 billion (Directorate for Statistics and Census 2007). Service sectors account for 80 percent of the local economy.

Hazards

Increases in sea and river levels, rising temperature and precipitation, along with increased frequency of extreme events like flooding caused by heavy (convective) rains and storm surges, as well as droughts are the primary climate-induced hazards for Buenos Aires. The city has a humid subtropical climate with long hot summers, and winters with low precipitation caused by the central semi-permanent high pressure center in the South Atlantic. This pressure system can cause strong south-southeast winds in the autumn and summer causing floods along the shores (Camillioni and Barros 2008).

Since the 1900s, the mean temperature has steadily increased on average by 0.2°C per decade. Likewise, over the last century, the precipitation in Buenos

Aires has increased on average by 22.8 millimeters per decade. For details on observed and projected temperature and precipitation trends for Buenos Aires see Figures 2 and 3. Regarding extreme events, there is an increase in frequency of extreme precipitation and associated city floods, see Table 3. Further, occurrences of precipitation events of more than 100 millimeters within 24 hours have nearly doubled—from 19 times between 1911 and 1970 to 32 times between 1980

FIGURE 2
Projected Temperatures Buenos Aires

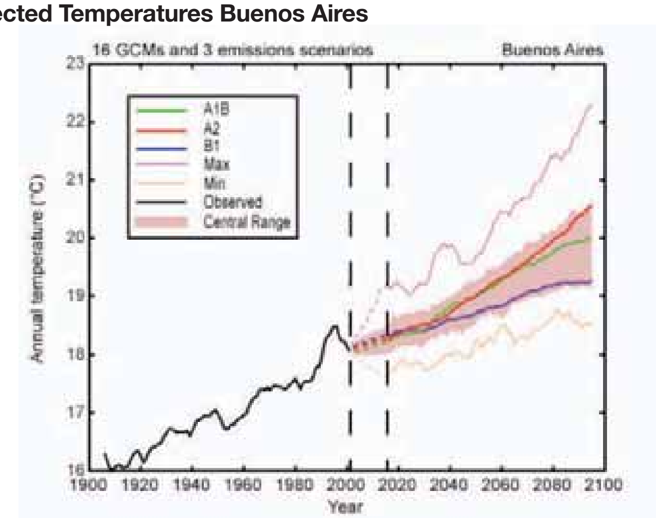
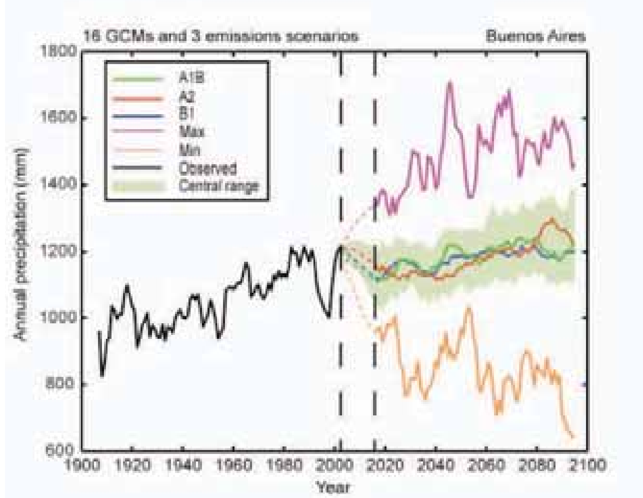


FIGURE 3
Projected Precipitation Buenos Aires



Source: Center for Climate Systems Research, Columbia University

TABLE 3
Extreme Events in Buenos Aires[1]

City	Extreme Temperatures	Extreme Precipitation
Buenos Aires	January & February 1987; December & January 1988; December & January 1996–97; January & February 2001; January 2002; January 2003; January 2004; December 2004	March 1988; May 2000; February 2003

Source: Center for Climate Systems Research, Columbia University

[1]Temperature extreme events (warm spells) were selected by finding the months that were over 1.5 standard deviations (2.0 for Lagos) from the full time series mean temperature for each city (the dataset was standardized). In case sufficient data is unavailable, a simple ranking procedure can be used to select the warmest months. This procedure would involve sorting and ranking the months and selecting the highest values.

The method used to select extreme precipitation events was similar to that used for temperature extremes. In this case, wet periods were selected by finding the months that were over 4 standard deviations from the 1900–2005 mean precipitation for each city. Lagos was the only city that had months that met the criteria for dry spells, which was greater than 1 standard deviation below the 1900–2005 mean. Again, a ranking procedure may be used for a quick assessment.

and 2000. Such observed increases in the quantity and frequency of extreme precipitation not only adversely affect urban infrastructure, but also damages private property and disrupts the economic and social functioning of the city.

Moreover, floods have become more frequent in the low-lying coastal zones since 1960 when the south Atlantic anticyclone was displaced southward bringing an increased frequency of easterly winds over the La Plata River. Storms with southeasterly winds, locally known as *sudestadas*, cause the River to swell, and result in the flooding of coastal zones that lie up to 2.8–5 meters above mean sea level, see Table 4.

TABLE 4
Frequency of Water Levels Above Mean Sea Level at the Buenos Aires Port

Frequency (years)	Height (meters)
2.5	2.50
5	2.80
11	3.10
27.5	3.40
79	3.70
366	4.00

Source: Barros et al., 2008.

BOX 1

Coast of the La Plata River

The La Plata River, an estuary, widens gradually from 50 kilometers at its source to 200 kilometers at its mouth; the river also increases in salinity along its exterior boundary towards the Atlantic Ocean. The riverbed has a gradual gradient (0.01 meter per kilometer), which favors maritime-type dynamics, with both lunar and wind-induced tides from the ocean. The "sudestadas" are local storms that can last from a few hours to two or three days, with strong winds from the southeast that push water towards the interior of the river and cause floods along the low Argentinean bank.

Source: Assessment of Impacts and Adaptation to Climate Change 2005.

Additionally, contributing to flood proneness, over the last century the average water level of the La Plata River has increased by 1.7 millimeters per year. If this trend continues, the coastal areas in and around the metropolitan agglomeration will experience frequent flooding as well as erosion along the coast (Camillioni and Barros 2008). A less likely, yet catastrophic climate-associated hazard is the salinization of the inner waters of the La Plata River, and the consequent contamination of the aquifers (Menéndez 2005).

Droughts caused by long dry spells in the La Plata River basin occasionally occur. However, these droughts affect cities located in the center and northwestern areas of the Basin more than Buenos Aires. This is because the section of the river along Buenos Aires has an average annual flow rate of 22,000 cubic meters per second. Thus, droughts were not considered a hazard for the city until 2008, when a surprising environmental problem with dry conditions emerged. That autumn, smoke from forest fires covered the city with soot for several weeks, posing a health hazard for the people of Buenos Aires.

Vulnerability

Buenos Aires is located along the shores of the La Plata River, spreading out over the *pampa*, a wide fertile plain, and the adjoining Parana river delta. As a result, the entire metropolitan area is less than 30 meters above mean sea level. As the city grew, several rivulets that formed the natural drainage system were replaced with a system of underground storm water drains (Falczuk 2008).

Spatial Distribution of Poor Versus Non-poor: During the 1990s the city experienced sprawl with developers building gated communities on the periphery of the metropolitan area, thereby extending the city over an area one and a half times the size of the CABA (Pírez 2002). With disparity on the rise and the migration of the non-poor from the city center to the periphery, the city has been further spatially segregated by income groups. This condition was further intensified with the economic crisis of 2001, which created the 'new poor' consisting of the middle class that now lacked incomes.

The precise distribution and enumeration of the slums in Buenos Aires is complicated by two additional factors. First is the process of 'urban invasions' whereby squatter settlements crop up sporadically across the city. Second, like all other urban data for AGBA, information on the poor is parsed into 30 administrative units. For this research, data for slums and other dilapidated housing in the CABA were derived from an Ombudsman survey in 2006 (see Table 5 for quantification of low-income housing), which found that about 20 percent of all households in the urban core of the AGBA live in poor housing conditions.

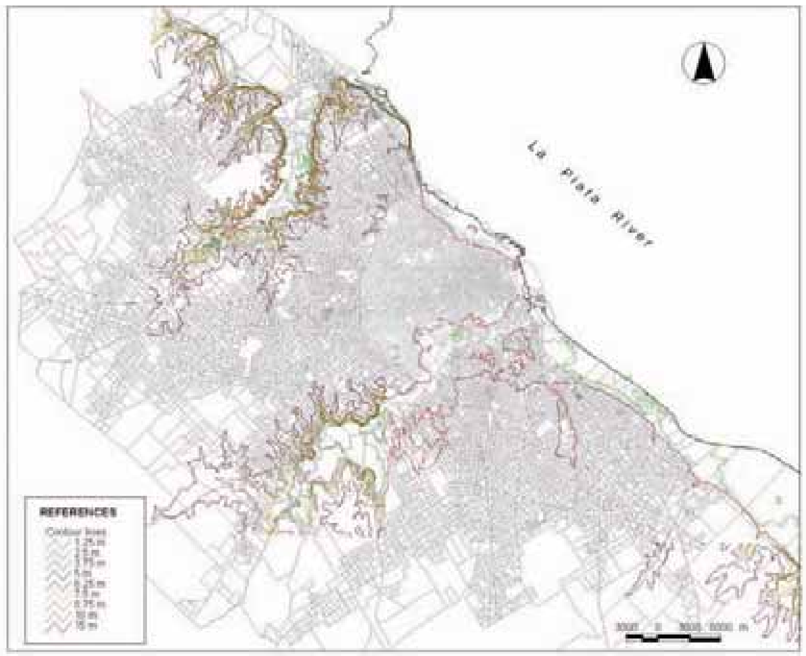
TABLE 5
Slum Population in Buenos Aires City (CABA)

Housing Types by Building Quality	Number of Units
Slums (villas miseria)	< 120,000
Properties of other people (inmuebles tomados)	200,000
Tenement house (casas de inquilinato)	70,000
Lodges	70,000
Rooms in relatives' houses, rental rooms, or overcrowded houses	120,000

Source: Office of the National Ombudsman, Buenos Aires 2006.

Additionally, the survey identified 24 new settlements with 13,000 inhabitants located under bridges or simply 'under the sky' (Defensoría del Pueblo de la Ciudad de Buenos Aires 2006). However, unlike developing-country slums, most households have land tenure and property rights related to their homes due to a well-established public housing program in Argentina. Mapping the spatial distribution of differential vulnerability of the poor and non-poor to floods and other hazards is critical to crafting a climate-risk assessment of Buenos Aires (see Figure 4).

FIGURE 4



Source: Silvia G. González adapted from Assessment of Impacts and Adaptation to Climate Change (2005).

Low elevation urban areas: In its present configuration, a quarter of the metropolitan area is susceptible to floods (Clichevsky 2002; Menéndez 2005). Urban expansion continues over the basins of the Matanza-Riachuelo, Reconquista, and Luján rivers, as well as the estuary of the La Plata River. These areas consist of a combination of new gated communities, real estate speculation sites, as well as illegal plots in the flood plain targeted toward the housing needs of the poor. With a lack of regulation governing such urban development and the creation of unprotected infrastructure in the flood plain, the vulnerability of this part of the city is increasing (Ríos and González 2005).

To assess the vulnerability of the low-elevation areas of the city a review of past urban floods was undertaken. As reported in newspapers and official assessments, floods impaired all modes of public and private transportation, including domestic flights, road, and rail; disrupted energy supplies, telephone lines and traffic lights; flooded buildings; and created an overall disruption of city life. Streets and cellars were waterlogged and people living in low-elevation neighborhoods in the suburbs were evacuated (González 2005). In sum, the economic costs were high. Unlike urban disasters in other developing countries, the death toll in Buenos Aires related to flooding disasters tends to be low. The primary costs are the disruption of the economic activity of the city and damage to public and private property.

As the metropolitan area has been expanding into the flood plain, a simulation to quantify the population vulnerable to sea level rise was conducted. Barros et al. (2008) observed that "Assuming little change in population density and distribution, under the scenario of maximum sea-level rise during the 2070 decade… the number of people living in areas at flood risk with a return period of 100 years is expected to be about 900,000, almost double the present at-risk population". The potential damage to public and private assets can be assessed from a recent survey that estimated that 125 public offices, 17 social security offices, 205 health centers, 928 educational buildings, 306 recreational areas and 1,046 private industrial complexes are currently at risk to floods.

A conservative estimate by Barros et al. (2008) states that at present the damage to real estate from floods is about US $30 million per year. Assuming a business-as-usual scenario, which includes a 1.5 percent annual growth in infrastructure and construction and no adoption of flood-protection measures, the projected annual cost of damages is US $80 and US $300 million by 2030 and 2070 respectively. These estimates do not include the losses to gated communities of the non-poor being built in the coastal area, largely located less than 4.4 meters above mean sea-level. Nor does this account for the loss in productivity of the labor force, which can be significant given the size of the population likely to be affected. Thus, the costs of not responding to climate change in the course of urban development are projected to be significant and disruptive.

Adaptive Capacity

The Argentinean government's response to global climate change has been dominated by mitigation efforts related to policies and programs to reduce greenhouse gas emissions (Pochat et al. 2006), with relatively little attention to adaptation. The lead national agency to address climate issues is the Secretariat for Environmental and Sustainable Development.

In 1993 Argentina became a signatory to the United Nations Framework Convention on Climate Change. In response, the federal government established the Office for Joint Implementation, but in 1998 this was renamed the Office for Clean Development Mechanisms. Further, in 1999 Argentina adopted the objectives of the Greenhouse Gases Reduction Programme, and in 2001 signed on to the Kyoto Protocol. To institutionalize the response to climate change, in 2003 a Climate Change Unit was established within the Secretariat for Environmental and Sustainable Development. In 2007, this evolved into the Climate Change Office. In addition, the government has been supporting a range of research programs, such as the National Programme on Climate Scenarios, which was initated in 2005. Through these institutional arrangements, first and second national reports were prepared in 1997 and 2006 respectively. The third version is under preparation (Pochat et al. 2006).

However, the roles and responsibilities of governmental agencies in regard to climate change remain fragmented, while adaptation responses, specifically at the city level, remain to be addressed. In addition, four ministries with a dozen departments and institutions are involved in flood monitoring and broader disaster management systems (Natenzon and Viand 2008). Gradually, lower levels of government such as the states and local authorities are taking an interest in addressing climate change mitigation and adaptation, and a range of stakeholders such as NGOs, the media, and citizen groups are participating.

Emerging Issues

Conflicting plans and multiple jurisdictions reduce the efficacy of climate change response plans at the city level as well (Murgida and González 2005). For example, in 2007 an office for Climatic Protection and Energy Efficiency was established within the Ministry for Environment of Buenos Aires City. With the arrival of a new administration in December 2007 this ministry was restructured into the Ministry of Environment and Public Space, with a new Environmental Protection Agency. The Office of Climate Protection and Energy Efficiency was dismantled despite the fact that previously initiated programs and projects like "Clean Production" and "Air Quality" continue to be implemented (Murgida 2007).

The primary obstacles to institutional action at the metropolitan level are lack of actionable climate information, as well as vertical and horizontal fragmentation of jurisdictions with divergent interests and responses. Administrative units within the AGBA address flood management but lack an integrated strategy. For example, within Buenos Aires City two different plans—the Urban Environmental Plan and the Buenos Aires 2015 Strategic Plan—are being implemented simultaneously but with a lack of effective coordination. Further, in practice there are two critical legislative instruments to regulate urban development in the city—namely the Building Code enacted in 1944 and the Urban Planning Code enacted in 1977. These are complemented by additional measures such as the Flood Control Plan, and post-2001 flood tax rebates for affected communities. However, these plans, codes, and norms are inconsistent. For instance, the Urban Planning Code incentivizes the occupation of vulnerable low-lying areas within the city, contradicting the flood prevention plans (González 2005).

Moreover, constantly changing organizational roles and responsibilities of government agencies tasked to address climate change pose a challenge. For instance, in 2005, the Buenos Aires State Government created a unit to address climate change within the provincial Ministry for Environmental Policy. This office continues to be operational under the new local government that was elected in 2007, but the unit has been moved to the Ministry of Social Development and has a reduced mandate. This lack of action orientation is compounded by a general lack of public awareness of the risks associated with climate change (Assessment of Impacts and Adaptation to Climate Change 2005).

Additionally, there is a mismatch in terms and scales. While the climate adaptation strategies like flood prevention and management need to take a long-term view and plan for the metropolitan region as a whole, most planning interventions address short-term needs and do not take a city-wide view (Murgida and Natenzon 2007). "By analyzing who participated in the planning process and in which areas they did so, it becomes evident that the vast majority of interventions were partial, some were very specific, and a few encompass different areas and spheres" (Pírez 2008). These issues become further complicated for the metropolitan region due to the overlap and aggregation of administrative units that lack a central governing authority.

The community of scientists and researchers has taken on an unusual task of coordinating climate-related programs and policies. A leading example of this effort was the launch of the Global Climate Change Research Program at Buenos Aires University (PIUBACC) in May 2007. The objective of this program is to map and link all research as well as city development projects within the metropolitan area so as to provide the government, civil society, and more specifically interested groups directly involved in climate change programs a holistic and scientific assessment of climate change risks. Additionally, the scientists are drawing transferable lessons from community knowledge on flood management along the La Plata River coast with a dual focus on the vulnerability of the poor and on adaptation to storm-surge floods (Barros et al. 2005).

4.2 Delhi[7]

Delhi has a population of 16 million inhabitants, and is rapidly urbanizing with a 3.85 percent annual growth rate over the 1990s, amounting to half a million migrants each year. In 1901 Delhi had 400,000 inhabitants. Furthermore, rising per capita incomes are increasing energy consumption, and over-stretching infrastructure. Delhi is a city of contrasts—in 2000, 1.15 million people were living below the National Poverty line. On the other hand, Delhi's Gross State Domestic Product at current prices was about US $27 billion during 2007 (Department of Planning 2008). At its widest dimensions, Delhi stretches 50 kilometers and occupies an area

---

[7] This response is primarily based on feedback and documents provided by the Department of Environment, Government of National Capital Territory of Delhi, India. In particular, summarized here are some pivotal actions taken by the government of Delhi under the leadership of the Chief Minister of Delhi including issues raised during her participation at the C40 Large Cities Climate Summit in New York in 2007.

of 1,400 square kilometers. To compound the challenges of rapid urban expansion and associated environmental risks, Delhi—like many Indian cities—faces several climate-related challenges and opportunities.[8]

Delhi has three distinct seasons—summer, winter, and monsoons with extreme temperatures and concentrated precipitation. Summers begin in mid-March lasting for three months and are dry and hot with temperatures peaking at about 40°C in the months of May and June. Monsoons are between mid-June and September; during which period Delhi receives most of its 600 millimeters of annual rainfall, with July and August getting as much as 225 millimeters each. Winters are dry and last from November to mid-March with December and January being the coldest months with temperatures as low as 7°C (Delhi 2009).

Hazards

The National Action Plan for Climate Change and related analysis provides an overview of climate change issues confronting India as recognized by the federal government (see Government of India 2002, 2008). Revi (2007) provides an overview of direct and derived climate-induced hazards in the context of urban India. Through a review of research on climate science, policy papers, and practitioner notes five hazards are identified. First, although there are uncertainties with scaling down global models such that they reflect regional climate conditions (like the Indian monsoon), temperature, precipitation, and sea-level are likely to rise. Mean extreme temperature, as well as maxima and minima, are expected to increase by 2 to 4°C, and are likely to result in an average surface warming of 3.5 to 5°C within this century.

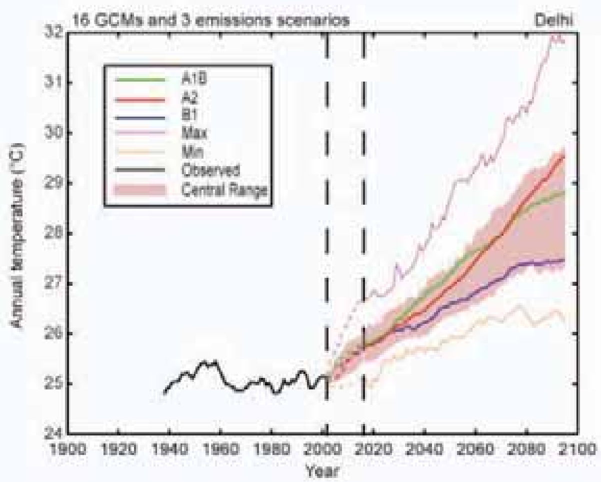
Second, average mean rainfall is projected to increase by 7 to 20 percent due to the increase in mean temperature and its impact on the Indian monsoon cycles within the latter half of this century. However, some drought-prone areas are expected to get dryer and flood-prone areas will very likely experience more intense periods of precipitation. Third, 0.8 meters is the projected centennial rise in mean sea level. Fourth, extreme events like the Mumbai flood of 2005 are expected to be more frequent in western and central India. A combination of these hazards expose the cities in this region to a range of other climate-induced extreme events like droughts, temporary and permanent flooding, both inland and in coastal areas, and cyclones.

For a summary of observed and projected temperature and precipitation for Delhi see Figures 5 and 6. Extreme minimum and maximum temperature events appear to be increasing. In December of 2006, Delhi had the lowest temperature since 1935 (0.2°C), and the media reported the death toll from the cold wave in north India to be over a 100 people in and around the region. The following summer in June 2007, Delhi had a maximum temperature of 44.9°C, once again taking a toll on the people of the city. While these extreme temperatures cannot

[8]To address similar issues in a global context, in February 2008 Delhi hosted the Delhi Sustainable Development Summit, which was attended by several world leaders. The summit explored links between sustainable development and climate change. Similarly, in 2002 Delhi hosted the United Nations Conference on Climate Change. The Delhi Declaration of 2002 was signed by representatives of 185 countries.

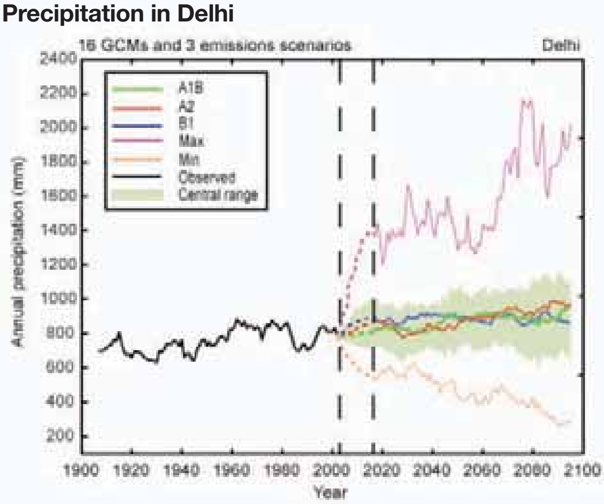
be directly linked to climate change, the challenge facing Delhi is variability in weather patterns and the potential for exacerbated extreme events due to climate change. Table 6 summarizes some of the months when temperature and precipitation were greater than 1.5 standard deviations from the mean, the hottest summer was in 1944, the coldest winter in 1935, and the wettest monsoon in 1958 (see Table 7), however recent years have seen similar extremes in temperature in 1978, 1988 and 1996 and precipitation in 1994, 1995, and 2003.

FIGURE 5
Projected Temperatures Delhi



Source: Center for Climate Systems Research, Columbia University.

FIGURE 6
Projected Precipitation in Delhi



Source: Center for Climate Systems Research, Columbia University.

TABLE 6
Past Extreme Events in Delhi

City	Extreme Temperatures	Extreme Precipitation
New Delhi	May 1978, April 1988, May 1996	July 1994, July 1995, June 2003

Source: Center for Climate Systems Research, Columbia University.

TABLE 7
Extreme Temperature and Precipitation in Delhi

	Maximum recorded temperature	Lowest recorded temperature	Maximum rainfall in 24 hours
Delhi	47.2 °C May 29, 1944	–00.6 January, 16, 1935	266.2 mm July 21, 1958

Source: Indian Meteorological Department, Regional Meteorological Center, Delhi.

Vulnerability

Delhi's physical infrastructure, social services, and slum populations make the city highly vulnerable. Demand for basic infrastructure services like water, electricity, and public transport far exceeds supply (Delhi Development Authority 2005). To add to the existing conditions, climate change induced variability in rains could worsen the severe shortage of drinking water in summers and aggravate floods during the monsoon season, making the existing energy shortage more challenging to address. With regard to transportation, Delhi has the highest per capita vehicular population in India—5.4 million automobiles for 15 million people. This poses a challenge for a city with mixed land use and varying urban densities within the metropolitan region to introduce effective modes of public transport. Carbon emissions from vehicles, traffic congestion, and increasing particulate matter all pose challenges. These and other challenges pose widespread public health risks to the inhabitants of Delhi. For example, lack of adequate sanitation facilities for the poor poses a problem for a rapidly growing city where a large proportion of population lives in slums.

The hyper-dense nature of the slums, despite Delhi's relatively low population density and the centrality of the poor in provision of services—from household help to a range of labor-intensive and low-wage tasks—poses an enormous challenge. The access to basic services is uneven across the city. While many parts of Delhi have high-quality infrastructure compared to other Indian cities, the slum dwellers lack access to many of these services. The extent of the vulnerability of the poor within the city is captured in the statistics offered by the Yamuna Action Plan, a river revitalization effort of the Government of India.

They observe that about 45 percent of the city's population live in a combination of unregulated settlements, including unauthorized colonies, villages, slums, and the like. Further, three million people live along the Yamuna River, which is prone to flooding, where 600,000 dwellings are classified as slums. Further, they observe that:

> ". . . nearly 62,000 units are estimated to be located in the river bed of Yamuna on both sides of its stretch along Delhi and on the embankments of a few major storm water drains such as Najafgarh drain, Barapulla drain etc. During dry weather these slum dwellers use open areas around their units for defecation. In this way, the entire human waste generated from these 62,000 units along with the additional wastewater generated from their household is discharged untreated into the river Yamuna."

Moreover, increasing competition for scarce basic services caused by the rapidly growing population of Delhi poses public heath as well as quality-of-life challenges. For example, some poor settlements lack basic amenities resulting in open defecation. Although the extent of the impacts remains to be assessed, potential climate change impacts added to current local environmental stresses are likely to intensify this crisis. Moreover, the low quality of housing in slums and their proximity to environmentally degraded land and flood-prone areas further exacerbate the vulnerability of the poor. Within the slums, climate-induced stress is likely to affect certain social groups more than others, particularly the elderly, women, and children.

Adaptive Capacity

The government of Delhi has made many efforts towards climate change mitigation, but there is lesser emphasis on adaptation. In addition to the issues of energy, water, and transportation, mitigation projects also encompass public health and other social and economic development efforts. Climate change mitigation efforts by the Government of Delhi were introduced first in the government departments and are being gradually expanded to include other stakeholders—schools, households, and firms. As seen below, most initiatives remain project-oriented (Department of Environment 2008). Some projects, such as the Bhagidari program, seek participation from neighborhood groups, private-sector associations, schools, and non-governmental organizations to enhance civil society engagement in environmental management, creating an expanded policy space for addressing climate change. Such collaboration holds the potential to address broader issues of climate adaptation by building awareness as well as capacity of stakeholders to respond. However, the most striking of all climate mitigation initiatives in Delhi so far is the establishment of the world's largest fleet of compressed natural gas (CNG)-fueled public transport in response to a Supreme Court order.

This has resulted in 130,000 CNG-powered vehicles, 145 CNG fuel stations, as well as improved vehicular emission standards like those adopted by the European Union. The fuel quality has been improved with respect to benzene, sulphur, and lead content. Yet the greatest lesson from this initiative is recognizing the diverse set of triggers and actors that can initiate adaptation and mitigation programs (see Box 2).

Some mitigation measures have co-benefits for adaptation as well. For instance, adoption of green building technology that is mandatory for the Public Works Department and the Airport Authority was introduced to address mitigation, but has adaptation benefits as well. Building guidelines include: (a) optimum energy efficiency in lighting, air-conditioning, and water systems; (b) eco-friendly heating, ventilation, and air-conditioning systems; (c) green screens for east and west building walls as well as for the roof; (d) maximizing natural lighting in buildings and using energy-graded glass; (e) use of certified eco-friendly building materials; (f) efficient water-dispensing technologies for kitchenware, toilets, and irrigation systems; (g) construction material from recycled products like fly ash bricks, recycled material in false ceilings, and recycled asphalt for roads; (h) landscape design to minimize soil erosion, reduce water usage, and ensure natural drainage systems. Expected greenhouse gas emissions reductions are 35 to 50 percent in general energy consumption and 100 percent in energy for water heating. Moreover, the New Delhi Municipal Council aims to reduce demand for energy by 15,000 kilowatts by 2009 and the Municipal Corporation of Delhi is making efforts to install compact fluorescent lamps, and capacitor banks to increase energy efficiency. Further, the government has a program that subsidizes electric vehicles and is encouraging the introduction of the Reva car, as well as battery-operated two and three-wheelers.

Delhi has expanded its forest cover over the past ten years. The city's greening program is considered to be one of the largest in the world. The forest cover has grown from 3 percent in 1998, to 19 percent in 2005. The city planted 1.7 million trees in 2007 and the forest cover grew to 300 square kilometers. To maintain the momentum, the city had plans to plant 1.8 million saplings in the fiscal year 2009, increasing the greenery cover to a total of 326 square kilometers. The city also has a policy to plant ten trees for every tree chopped down. This project is in collaboration with several stakeholders including school children, housewives, and neighborhood associations. The saplings are distributed gratis through a host of vendors. This afforestation effort is part of a CDM project proposal. To scale-up mitigation efforts, the Delhi government has established a program to raise awareness about carbon credits and clean development mechanisms among

BOX 2

Change Agents for CNG-Operated Public Transport in Delhi

In 1995 a World Bank study found that poor air quality posed health hazards for households in Delhi. The study estimated that air pollution caused 1 death every 70 minutes in Delhi, and branded Delhi as one of the most polluted cities in the world (Brandon and Hommann 1995). Subsequently, Cropper et al. also a World Bank study, argued that these death tolls may have been overestimated (1997), however the initial report generated public outrage in the city, and the Centre for Science and Environment (CSE 2009) started a campaign demanding clean air. The health impacts of suspended particulate matter (SPM) on lungs became apparent, and emissions from poorly managed polluting public transport were identified as one of the main causes of poor air quality.

The campaign mustered citizen support through involvement of professional associations, media, academia, and other stakeholders. The advocacy campaign involved bringing the message directly to the attention of the national political leadership. In response to the public outrage, the Supreme Court issued a judgment in 1998 requiring the government of Delhi to stem air pollution by introducing CNG-operated public transport, and to augment the supply of mass transit within a prescribed timeframe of 3 years, as well as required adoption of stringent emission standards within 5 years.

Automobile firms resisted the change and found some support within the government that raised safety and viability concerns. In response, the Supreme Court issued stringent directives including appointing a CNG czar to ensure compliance of new regulations, instituted large penalties for defaulters—including state and federal agencies—and increased funding of research and development. The Supreme Court, by now the principal driver of change, followed up with further directives. Both supply and demand for CNG and safety regulations were addressed through institutional mechanisms.

In about five years (1998-2002) all public transport in Delhi was converted to CNG-operated retrofitted buses. Further, this effort triggered several projects to increase supply of efficient and clean public transport systems like the Delhi metro and the Bus Rapid Transport all contributing to emission reductions as part of climate change mitigation efforts within the city. However, the key lesson illustrated here is that change agents are diverse—like in this case researchers, civil society, and the supreme court—and require creative and persistent efforts as well as the willingness to learn by doing.

Author: Herrera-Sosa, K.; *Reference:* Centre for Science and Environment (www.cseindia.org), and C40 Cities (www.c40cities.org).

various departments. The objective is to develop a holistic approach towards reducing green house gas emissions and developing projects that can redeem carbon credits. These mitigation projects can prove vital for adaptive capacity as well. For example, green roofs and walls, and tree-planting help to cool the urban environment and reduce heat island effects, as do many of the energy-efficiency projects related to buildings.

While the neglect of adaptation remains a concern, another co-benefit to mitigation efforts in Delhi is the climate change awareness and administrative capacity being built as a result of mitigation projects that may help as adaptation projects and policy measures are introduced. Not only is the government developing financial incentives to introduce programs and adopting a multi-sectoral approach that involves various departments within the city jusrisdiction, they are also learning to utilize mechanisms like the UNFCC's Clean Development Mechanism (CDM) funds that will be equally relevant for adaptation. Illustrations of such efforts are the CDM projects and certified emission reductions (CERs) in the water, energy, and transport sectors.

Delhi Jal Board—the department in charge of Delhi's Water and Sanitation service—has energy-efficiency improvement programs in water supply, wastewater treatment, and methane recovery. Delhi Jal Board has proposed a project under the Clean Development Mechanism (CDM) with the objective to reduce greenhouse gas emissions. The Municipal Corporation of Delhi also has an ongoing project, sanctioned by the World Bank, for methane recovery and reuse from three landfill sites. The project involves landfill gas extraction, gas testing, a feasibility study, and technical design of the project. Expected emission reduction from this project is three million tons of carbon dioxide equivalents. Further, electricity generating companies are taking initiatives to enhance efficiency of power plants through improvement in heat rates. Renovation of 210 megawatt units under a proposed CDM project is expected to improve heat rates by 25 percent—from 200 to 250 kilocalories per kilowatt hour. The expected emissions reductions are 128,000 tons of carbon dioxide per unit.

Efforts by the electricity distribution companies include: (a) installation of electronic chokes and compact fluorescent lamps (CFL)—installing CFLs in homes can earn 1.22 million tons of CERs annually; (b) mandatory installation of solar water heating systems in buildings that are 500 square meters and more; (c) installation of energy-efficient water pumps, power capacitors, as well as foot and reflex valves for farmers; (d) promotion of low energy light-emitting diodes (LEDs) at traffic lights; and (e) performance ranking among power distribution companies. Likewise, the Municipal Corporation of Delhi's integrated waste-management project—waste to energy—proposes to convert 2,050 million tons of municipal solid waste into 16 megawatts of power. The anticipated greenhouse gas emissions reductions from this project are substantial. The project is registered with UNFCCC to earn 2.6 million CERs over ten years.

In the transport sector, the Delhi Metro Rail Corporation has provided the city with a subway system. Its efforts to mitigate emissions include: reduction in net energy consumption through introduction of regressive brakes that convert kinetic energy released during deceleration of the train and generate electricity that is supplied to the overhead electric supply lines. The expected emission reduction as registered with the UNFCCC is 400,000 CERs over ten years and is the world's first railroad project that includes carbon credits.

Finally, the government has several schemes through which it gives subsidies, low-interest loans, matching grants—like, buy one-get one free—to promote the use of less energy-intensive technologies. Although these instruments work well for capital investment like installing a solar heater or roof-top water harvesting system, these incentives often fail to sustain the projects over time because operation and maintenance are ignored. Thus, the net impact of such programs is often low.

Emerging Issues

While Delhi is making major efforts towards mitigation of climate change through carbon emission reductions and other environmental improvements, there is a significant lack of awareness about the need for adaptation to climate change. Therefore, the city has not yet planned for adaptation.

Further, Delhi's response to climate change is often less than effective as well as piecemeal because its efforts are primarily project-oriented. In the experience of the Delhi government, incentives—subsidies and grants—have been effective for initiating projects, but operation and management frequently remain neglected. For instance, subsidies to install rainwater-harvesting systems have created demand but subsequent maintenance is too often ignored and many systems fall into disrepair. Such experiences hold the potential to inform adaptation efforts as well.

Gradually the city is developing a programmatic approach, but there is a need to coordinate between departments and among levels of government. For example, while the Prime Minister of India has recently released the National Action Plan for Climate Change, Delhi's local efforts will need to be reconciled with regional and national priorities.

4.3 Lagos

Lagos is Africa's second most populous city, which grew explosively, from 300,000 in 1950 to an expected 18 million by 2010, when it will be ranked as one of the world's ten largest cities. The metropolitan area, an estimated 1,000 square kilometers, is a group of islands surrounded by creeks and lagoons and bordered by the Atlantic Ocean. With a GDP triple that of any other West African country, Lagos is the commercial and industrial hub of Nigeria. Lagos is home to many industries, and critical infrastructure, and has greatly benefited from Nigeria's natural resources of oil, natural gas, coal, fuel wood, and water. For an overview of the state of Nigerian cities see UN-Habitat (2004).

The climate of Lagos is affected by oceanic and atmospheric interactions both within and outside its environment, in which the Inter-Tropical Convergence Zone (ITCZ) plays a controlling factor. The movement of the ITCZ is associated with the warm humid maritime Tropical air mass with its southwestern winds and the hot and dry continental air mass with its dry northeasterly winds. Maximum temperatures recorded during the dry season are high and range from 28–33°C when the region is dominated by the dry northeast trade winds. Minimum temperature of about 24–26°C is experienced during the wet season of May to September.

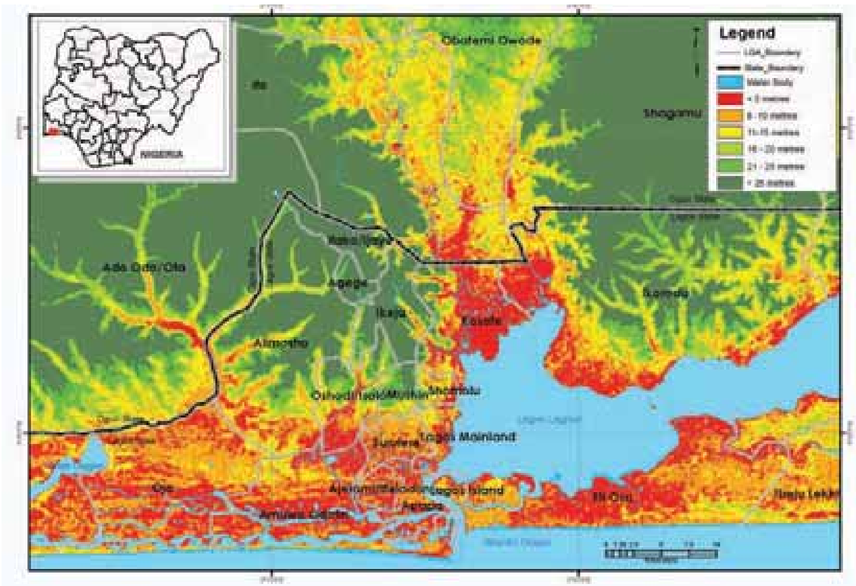
The city of Lagos experiences relatively high to very high temperatures throughout the year. The mean annual temperature is about 28°C and the maximum and minimum temperature is 33°C and 26°C respectively. High to very high monthly rainfall is also experienced between May and November, although significant variations in monthly rainfall peak values are experienced. For example, between 1950 and 2006, more than 10 instances were recorded with a maximum rainfall of over 700 millimeters. Minimum monthly rainfall of less than 50 millimeters is experienced between December and March. Occasionally, extreme precipitation events are experienced in June. On June 17, 2004, for example, 243 millimeters of rain was experienced in Victoria Island and the Lagos environs. This resulted in flooding of streets and homes, collapsing of bridges, and massive erosion of the main road linking Lekki to Lagos Island. About 78 percent of the total rainfall amount for the month was experienced in one day in June. The city was ill-prepared for that amount of rainfall.

Hazards

This trans-administration megacity is bounded in the south by the Atlantic Ocean (Bight of Benin), in the east by the Lagos Lagoon and the southwest by the Badagry Creek. The western and northern limits merge into the gently undulating agricultural lands of Ado Odo/Ota local government area, and the north-central edge of the city is located in the Ogun River flood plain (see Figure 7 for topography identifying low lying areas that overlap with built-up areas and are prone to flooding).

A study by Ekanade et al. (2008) has localized the nature and magnitude of climate change hazards at the city level using different (GHG) emission scenario models. The IPCC (2001a) Special Report on Emission Scenarios A2 and B1

FIGURE 7
Lagos Topography—Low Lying Areas Overlap With Built-Up Areas, Particularly Slums



Source: Authors' analysis, derived from the Shuttle Radar Topography Mission (SRTM) Digital Terrain Model (DTM) data. The DTM data was color-coded, clipped for the study area, and the administrative map superimposed.

climate change scenarios were utilized to project 30-year time-slices for temperature and rainfall values for the City of Lagos and Port-Harcourt and the coastal areas of Nigeria. This study did not, however, project sea level rise.

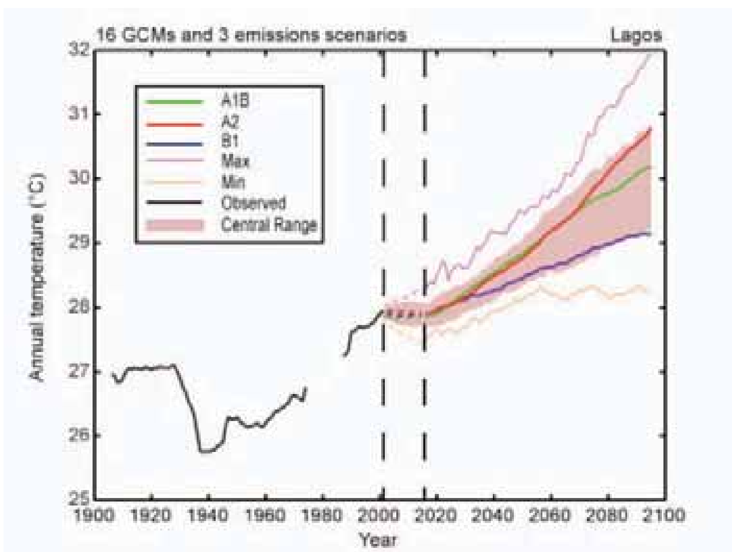
Temperature: Records from two stations (Ikeja and Lagos) used in this analysis show that monthly maximum temperatures are increasing at about 0.1°C per decade from 1952 to 2006, while monthly minimums are decreasing at about 0.5°C per decade; since the 1900s average temperature has increased 0.07°C per decade (Figure 8). At the extremes, monthly maximum temperatures for Lagos have reached above 34°C during seven of the last twenty years. The number of heat waves in Lagos has also increased since the 1980s (see Table 8). There are very few incidences of unusually cold months of less than 20°C since 1995. Projected temperature for Lagos for 2050s anticipates a 1 to 2°C warming (see Figure 8).

TABLE 8
Extreme Events in Lagos

City	Extreme Temperatures	Extreme Precipitation
Lagos	March 1988, March 1990, February 1998, March 1988, March 2001, March 2002, February 2003, March 2003, August 2004	May 1958, June 1962, July 1968, August 1998, November 1998

Source: Center for Climate Systems Research, Columbia University.

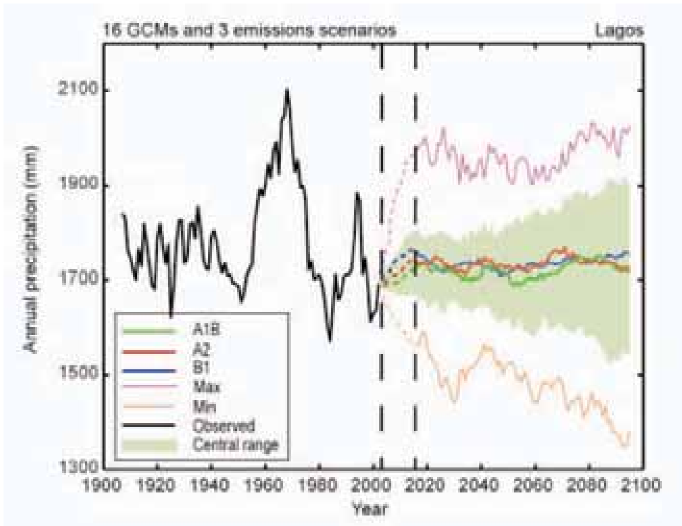
FIGURE 8
Projected Temperatures Lagos



Source: Center for Climate Systems Research, Columbia University.

Precipitation: According to historical records, the total annual precipitation in Lagos has decreased by 8 millimeters per decade since 1900 (see Figure 9). In keeping with the overall precipitation trends, most of Lagos has experienced decreases in rainfall amounts during the rainy season. For example, between 1950 and 1989 more than 20 months experienced rainfall amounts of over 400 millimeters. In the recent period between 1990 and 2006 however, very few (4) rainy months recorded over 400 millimeters of rain. In the 21st century, precipitation in Lagos is expected to be less frequent but more intense, projected precipitation for Lagos for 2050s anticipates an uncertain 5 percent change in mean precipitation.

FIGURE 9
Projected Precipitation Lagos



Source: Center for Climate Systems Research, Columbia University.

Storm surge is a concern. Lagos, as well as the entire Nigerian coast is projected to experience more storm surges in the months of April to June and September to October annually. This increase in storm surges is projected to be accompanied by greater extreme wave heights along the coasts. According to Folorunsho and Awosika (1995) the months of April and August are usually associated with the development of low-pressure systems far out in the Atlantic Ocean (in the region known as the 'roaring forties'). Normal wave heights along the Victoria beach range from 0.9m to 2m. However, during these swells, wave heights can exceed 4m. The average high high-water (HHW) level for Victoria Island is about 0.9m above the zero tide gauge with tidal range of about 1m. However, high water that occurs as surges during these swells has been observed to reach well over 2m above the zero tide gauge. These oceanographic conditions are aggravated when the swells coincide with high tides and the spring tide.

An extreme event, which can be considered a case study for future threats, was observed between August 16 and 17, 1995, when a series of violent swells in the form of surges were unleashed on the whole of Victoria Beach in Lagos. The most devastating of these swells occurred on August 17, 1995, between 06.00 to 10.00 GMT. The surge coincided with high tide thus producing waves over 4 meters high flooding large parts of Victoria Island. Large volumes of water topped the beach and the Kuramo waters, a small lagoon separated from the ocean by a narrow—fifty meters wide—strip of beach, was virtually joined to the Atlantic Ocean. Many of the streets and drainage channels were flooded resulting in an abrupt dislocation of socio-economic activities in Victoria and Ikoyi Islands for the period of the flood.

Sea Level Rise: Coastal erosion is very prevalent along the Lagos coast. The Bar beach in Lagos has an annual erosion rate of 25 to 30m. Earlier IPCC scenarios have been used to estimate the effects of 0.2, 0.5, 1 and 2.0m sea level rise for Lagos. Along with coastal flooding, and erosion, another adverse effect of sea level rise on the Lagos coastal zone as earlier assessed by Awosika et al. (1992, 1993a, 1993b) is increased salinization of both ground and surface water. The intrusion of saline water into groundwater supplies is likely to adversely affect water quality, which could impose enormous costs on water treatment infrastructure.

Vulnerability

As a group of islands, Lagos is bordered by mainland Nigeria to the north and west, other islands to the east and the Atlantic Ocean to the south. Lagos has an extremely dense slum population, many of whom live in floating slums. These are neighborhoods that extend out into the lagoons scattered throughout the city. The Barrier Lagoon system in Lagos, which comprises Lagos, Ikoyi, Victoria and Lekki, will be adversely affected through the estimated displacement of between 0.6 to 6 million people as a result of sea level rise of between 0.2 to 2m (Awosika et al. 1993a).

In their study of the impacts and consequences of sea level rise in Nigeria, French et al. (1995) recommended that buffer zones be created between the shoreline and the new coastal developments. A more generalized multi-sectoral survey of Nigeria's vulnerability and adaptation to climate change was funded by the Canadian International Development Agency (CIDA) through its Climate Change Capacity Development Fund (CCCDF). This study has served to create awareness of climate change issues and of the need for manpower development.

Even more worrisome is the general sensitivity of the megacity to climate change due to its flat topography and low elevation location, high population, widespread poverty, and weak institutional structures. Many more vulnerabilities stem from these characteristics including the high potential for backing up of water in drainage channels, inundation of roadways, and severe erosion. The barrier lagoon coastline in the western extremity, including the high-value real estate at Victoria Island and Lekki in Lagos, could lose well over 584 and 602 square kilometers of land respectively from erosion, while inundation could completely submerge the entire Lekki barrier system (Awosika et al. 1993a, 1993b), (see Figure 10). Moreover, flooding poses greater threats to the urban poor in several African cities (Douglas and Alam 2006).

FIGURE 10
Lekki Phase I Affluent Neighborhood (sand filled)

Source: IKONOS satellite imagery.

Intense episodes of heat waves will likely severely strain urban systems in Lagos, by inflicting environmental health hazards on the more vulnerable segments of the population, imposing extraordinary consumptions of energy for heating and air conditioning where available, and disrupting ordinary urban activities.

It is very likely that heat-related morbidity and mortality will increase over the coming decades; however, net changes in mortality are difficult to estimate because, in part, much depends on complexities in the relationships among mortality, heat, and other stresses. High temperatures tend to exacerbate chronic health conditions. An increased frequency and severity of heat waves is expected, leading to more illness and death, particularly among the young, elderly, frail, and poor. In many cases, the urban heat island effect may increase heat-related mortality. High temperatures and exacerbated air pollution can interact to result in additional health impacts.

Impacts are projected to be widespread as urban economic activities will be likely affected by the physical damages caused to infrastructure, services, and businesses, with repercussions on overall productivity, trade, tourism, and on the provision of public services.

Built-up Area and Population Density: The contiguously built-up area of Lagos megacity is about 872 square kilometers. This is located within 17 local government areas in Lagos State with a total of 642.22 square kilometers (73.6 percent) and 4 local government areas in Ogun State with 229.8 square kilometers (26.4 percent). The Alimosho local government area has the largest built-up area of about 144 square kilometers while Lagos Island, also in the Lagos State sector has the smallest built-up area of about five square kilometers. Most of the local government areas in Lagos are almost completely built with virtually no further space to grow.

Lagos megacity is one of the world's fastest growing urban centers. The UN-Habitat (2006) estimated the city's population to be about 15 million in 2006 with 600,000 additional migrants added each year, and projected its population to reach 20.2 million by 2010.

The city's high aggregate population is an indication of its enhanced sensitivity to hazards. Thus, the effects of any negative consequences of climate change and climate variability extremes are likely to be felt by a large number of people, most especially the urban poor living on the marginal flood-prone areas of the city (see Table 9 and Figure 7). The built-up area breakdown shows that the Lagos State side of the megacity, which is made up of about 74 percent of the built-up area, has about 85 percent of the megacity's population, while Ogun state, with 26 percent of the built-up area, accounts for about 15 percent of the megacity's population. The elevation of the built-up area of the city ranges between 1m in the coastal areas to about 75 meters above sea level at its northern fringes (Ogun State Government 2005).

TABLE 9
Estimation of Internally Displaced People by Sea Level Rise Scenarios in Lagos

(in meters)				
Sea Level Rise Scenarios	0.2 m	0.5 m	1.0 m	2.0 m
By shoreline types, number of people displaced (in millions)				
Barrier	0.6	1.5	3.0	6.0
Mud	0.032	0.071	0.140	0.180
Delta	0.10	0.25	0.47	0.21
Strand	0.014	0.034	0.069	0.610
Total	0.75	1.86	3.68	10.00
Percentage of Total Population	0.07	1.61	3.20	8.70

Source: Awosika et al. 1992.

The average population density of the city's constituting local government areas is about 2,094 per square kilometer with a minimum of 164 per square kilometer in Owode Obafemi local government area of Ogun State and a maximum of 55,939 per square kilometer in Ajeromi Ifelodun local government area in Lagos State. A better picture of the city's high population density can be inferred by a breakdown of each local government area's population density by the built-up areas. The local government areas in the Lagos State side have an average density of 13,194 per square kilometer. Ajeromi, Ifelodun local government area has a staggering density of 60,204 per square kilometer.

Lagos City, Urban Form, and Poverty: In 1983, 42 slums or blighted areas covering 1,622 hectares were officially documented by Lagos State. The number rose to about 62 out of the 2,600 communities in the state in 1995 (UN-Habitat 2006). Due to the lack of secure land tenure slum communities are vulnerable to the threat of eviction (Morka 2007). More recently, the Report of the Presidential Committee Redevelopment of Lagos Mega-City (Federal Republic of Nigeria 2006) put the number of slum or blighted areas at over 100 in the Lagos portion with another 31 areas in the Ogun State portion of the megacity. The growth of the slums was also described in the report as a testimony to the city's difficulties in producing affordable housing for the urban poor. A 2002 survey in the megacity by Nubi and Omirin (2006) similarly revealed that over 70 percent of the built-up area of the metropolis is blighted. Most of the slums are located on marginal lands that are mainly flood-prone with virtually no physical and social infrastructure (see Figure 7). Lagos State government has, however, been making attempts at the inventory, management and upgrade of some of the slums through the Lagos State Urban Renewal Authority (LASURA) and the World Bank (IDA)-assisted Lagos Metropolitan Development and Governance Project (LMDGP).

Some of the planned and affluent neighborhoods in many parts of the city still experience flooding during "normal" rainfall. This may be attributed to the little-to-no attention often given to the provision and maintenance of sewer and storm drains in these supposedly "planned" affluent neighborhoods. For instance, Ikoyi, one of the most highly priced neighborhoods in the city, was actually developed from an area originally covered by about 60 percent wetland. Also, Victoria Island and Lekki neighborhoods were formally low-lying barrier lagoon systems interspersed by wetlands and tidal flats with an elevation of about 0-3 meters before they were developed (see Figure 10).

Urban poverty has been described as one of the most daunting challenges currently facing the city's administrators (UN-Habitat 2006). The average monthly household income for the 1.1 million inhabitants of the 158,000 households in the LMDGP project was about US $170 (Abosede 2006, 2008). Also, despite the city contributing more than 60 percent of Nigeria's Gross Domestic

Product, 65 percent of national investments and 65 percent of the nations Value Added Tax (VAT), about 65 percent of the residents are estimated to live below the poverty level. The deplorable state of the urban form and poverty is indicative of the expected low resilience of most of the inhabitants of the city to external hazard stressors such as those often associated with climate extreme events.

Adaptive Capacity

Even with active membership in the C40 Large Cities Climate Leadership network, Lagos megacity still does not have a comprehensive analysis of the possible climate risks facing it. The Goethe Institute and the Heirich Boll Stiftung Foundation, Lagos were NGOs at the fore of raising the alarm specifically on the vulnerability of the city to inundation due to the sea level rise associated with climate change.

It would be untrue to say that there are no activities on climate change in Nigeria, most especially by the scientific community, but a disconnect does exist between the scientists, the people, and the political class. The implication is that there is an urgent need to address the obvious lack of awareness of the vulnerability of Lagos to climate change and the need to begin to plan adaptation strategies. Recently, tackling the problem of flooding and coastal erosion has been given more attention by the Lagos State government in the form of a sea wall along Bar Beach in Victoria Island. This activity, however, is evidence that local awareness appears to be lacking of the full scope of the city's vulnerability to climate change.

Although the attention of city managers is more focused on filling its long physical infrastructural gap due to years of neglect, the lack of concern or awareness of likely sea level rise in Lagos is worrisome. There continues to be sand-filling of both the Lagos Lagoon and the Ogun River flood plain in the Kosofe local government area to about 2 meters above sea level for housing developments. Such activities need to be done with projections of sea level rise due to climate change as part of the planning process.

Emerging Issues

Currently, the leading actor on climate change issues in the city is the Lagos State Government, which has been influenced by its membership in the C40 Large Cities Climate Summit. Some of the mitigation actions being pursued by the Lagos State Government in the city include:

1. Improvement of the solid waste dump sites that are notable point sources of methane—a greenhouse gas—emissions in the city.
2. The new bus rapid transport (BRT) mass transit system is already shopping for green technology to power vehicles in its fleet.

3. Commencement of tree planting and city greening projects around the city.
4. Proposed provision of 3 air quality monitoring sites for the city.

The full picture of the nature of climate change and variability, its magnitude, and how it will affect the city is yet to be analyzed to support any informed adaptation actions. Thus, the climate risk reduction adaptation actions presently taken in the city are primarily spin-offs from the renewed interest of the city's management in reducing other risks and taking care of developmental and infrastructural lapses, rather than being climate change-driven. Some of these adaptation activities include:

1. The sea wall protection at Bar Beach on Victoria Island to protect against coastal flooding and erosion due to storm surges.
2. Primary and secondary drainage channel construction and improvement to alleviate flooding in many parts of the city.
3. Cleaning of open drains and gutters to permit easy flow of water and reduce flooding by the Lagos State Ministry of Environment Task Force locally referred to as "Drain Ducks."
4. Slum upgrade projects by the Lagos Metropolitan Development and Governance Project.
5. Awareness and education campaigns such as the formation of Climate Clubs in Primary and Secondary Schools in Lagos, and the organization of training sessions and workshops on climate change issues.

Due to the increasing activity in the Ogun State sector of the city, a regional master plan for the years 2005–2025 (Ogun State Government 2005) has been developed for its management. However, the issue of climate change risks to infrastructures and the different sectors such as water and wastewater (Iwugo et al. 2003), health, energy and the like is not yet reflected in the report.

"Normal" rainfalls are known to generate extensive flooding in the city largely because of inadequacies in the provision of sewers, drains, and wastewater management even in government-approved developed areas. Consequently, an increase in the intensity of storms and storm surges is likely to worsen the city's flood risks. Since the local governments are very close to the people and the communities threatened by climate risks, there is the need to create the awareness at the local government level. There is an urgent need to empower them intellectually, technically, and financially to identify, formulate, and manage the climate-related emergencies and disasters, as well as longer-term risks more proactively.

4.4 New York

With 8.2 million people, a $1.1 trillion GDP (Bureau of Economic Analysis, 2008) and an operating budget of over $40 billion, New York City is the largest city in the United States both in population and economic productivity (The City of New York, 2007, 2009). The distribution of wealth within the City, however, has been described as an "hourglass economy" where there is a shrinking of the middle class and growth in both the upper- and lower-income populations (Rosenzweig and Solecki 2001).

New York City is an archipelago with five boroughs spread out over three islands—Long Island, Manhattan and Staten Island—and the mainland of the United States. Once a major manufacturing center, New York is now one of the world's most important international financial hubs. As a coastal city, most of New York City sits at a relatively low elevation with approximately 1 percent of the city below 3 meters (10 feet) (Rosenzweig and Solecki 2001). Much of Manhattan's very low-lying land is home to some of the most important economic infrastructure in the world. Lower Manhattan, including the Wall Street financial district, and portions of both LaGuardia and John F. Kennedy airports sit at this low elevation.

New York City has a temperate, continental climate characterized by hot and humid summers as well as cold winters and consistent precipitation year round. Using a baseline period of 1971–2000, records show an average temperature of 12.7°C with precipitation averaging 109 to 127 centimeters per year during the period 1900-2005. Recent climate trends show an increase in average temperature of 1.4°C since 1900 and a slight increase in mean annual precipitation (New York City Panel on Climate Change [NPCC] 2009).

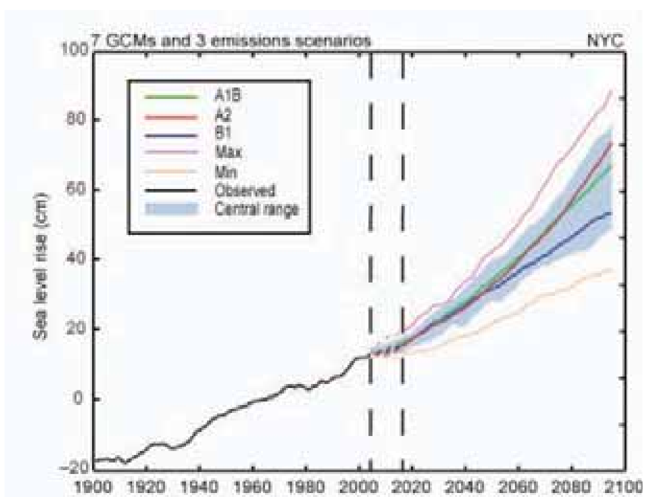
As with other cities, climate change risks in New York City are a function of the hazards that the city faces, the vulnerability of its population and infrastructure to those hazards, and the adaptive capacity of the city to address climate change mitigation and adaptation needs. Hazards come in the form of increasing incidence of heat waves, droughts and floods, and sea-level rise and associated storm surges. Adaptive capacity in New York City has been bolstered by the high-level adoption at the Mayoral and the State levels of the need to develop climate change adaptation strategies. Agencies, departments, and public authorities are now developing and being provided with the tools necessary to undertake climate change mitigation and adaptation strategies.

Hazards

Each year New York City is susceptible to mid-latitude cyclones and nor'easters, which peak from November to April. These storms contribute greatly to coastal erosion of vital wetlands that help defend areas of the city from coastal flooding. Tropical cyclones (hurricanes) also have the potential to reach New York City usually during the months of August to September. There is some indication that intense hurricanes will occur more frequently in the future, but this is an area of active scientific research.

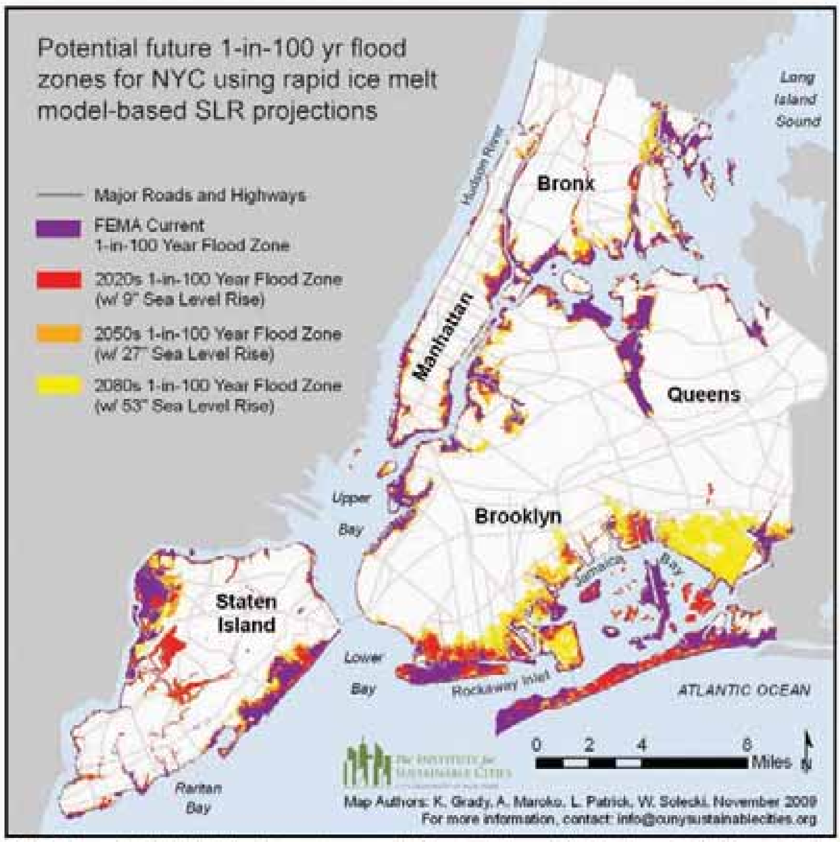
Based on climate model projections and local conditions, sea level is expected to increase by 4 to 12 centimeters by the 2020s, and 30 to 56 centimeters by the 2080s (see Figure 11); when the potential for rapid polar ice melt is taken into account based on current trends and paleoclimate studies, sea level rise projections increase to between 104 to 140 centimeters (NPCC 2010). With some of the world's most valuable and important economic activity taking place on Wall Street, the economy of the City, the United States, and arguably the world is vulnerable to the effects of enhanced coastal flooding due to sea level rise (See Figure 12). The New York Stock Exchange is the largest stock exchange in the world (NYSE Euronext 2009) and sits at an elevation of less than three meters (Rosenzweig and Solecki 2001). The possibility of inundation during coastal storms is greatly enhanced with the projected effects of sea level rise.

FIGURE 11
Projected Sea Level Rise New York City



Source: Center for Climate Systems Research, Columbia University.

FIGURE 12
Potential Future 1-in-100 Year Flood Zones for New York City Using Rapid Ice Melt Model-Based Sea Level Rise Projections

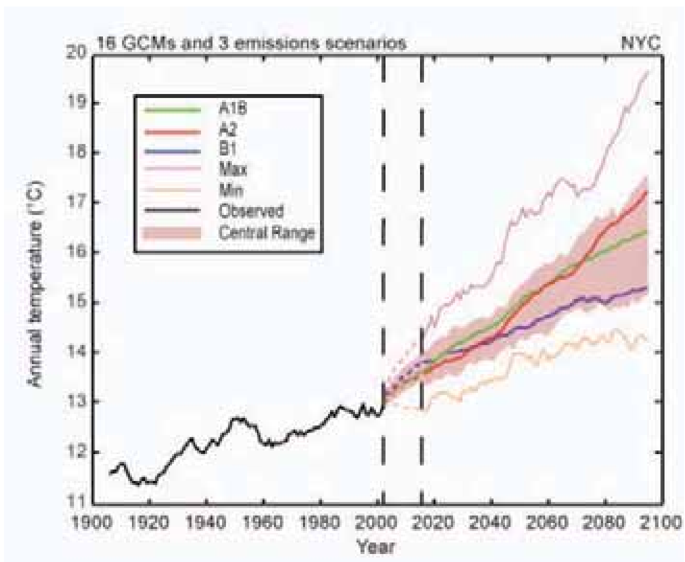


Note. This map is subject to limitations in accuracy as a result of the quantitative models, datasets, and methodology used in its development. The map and data should not be used to assess actual coastal hazards, insurance requirements or property values or be used in lieu of Flood Insurance Rate Maps issued by FEMA.

Interpretation. The floodplains delineated above in no way represent precise flood boundaries but rather illustrate three distinct areas of interest: 1) areas currently subject to the 1-in-100 year flood that will continue to be subject to flooding in the future, 2) areas that do not currently flood but are expected to potentially experience the 1-in-100 year flood in the future, and 3) areas that do not currently flood and are unlikely to do so in the timeline of the climate projection scenarios used in this research (end of the current century).

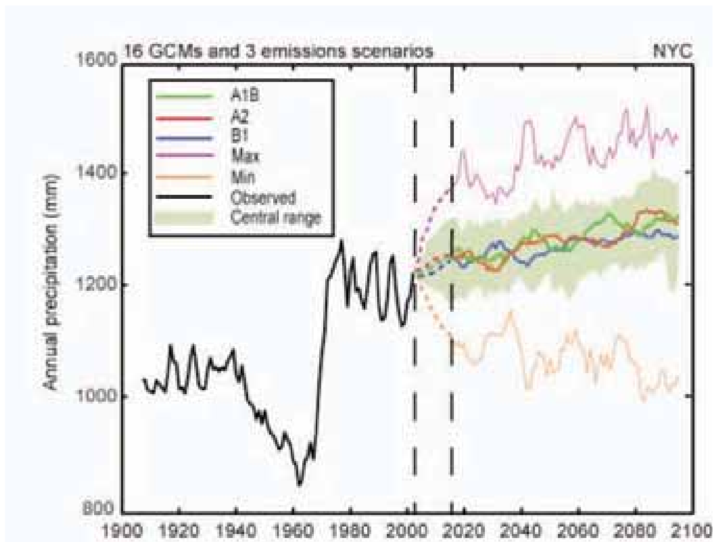
Another hazard to New York City as a result of climate change is rising mean temperature, along with the associated increase in heat waves. The annual mean temperature in New York City has increased nearly 2˚C since 1900 (NPCC 2010). Climate models predict that the average temperature will increase between 1 to 1.5°C by 2020 and 2 to 4°C by the 2080s as seen in Figure 13 (NPCC 2010). As defined by the New York Climate Change Task Force, a heat wave is any period of three straight days with a temperature over 32˚C. The frequency of heat waves is projected to increase as the number of days over 32˚C increases. These higher temperatures will also intensify the urban heat island in New York City, because urban materials absorb radiation throughout the daytime and release it during the night causing minimum temperatures to rise (Rosenzweig and Solecki 2001; Kinney et al. 2008). These sustained, higher temperatures exacerbate the effects of heat on humans (Basu and Samet 2002).

FIGURE 13
Projected Temperatures New York City



Source: Center for Climate Systems Research, Columbia University.

FIGURE 14
Projected Precipitation New York City



Source: Center for Climate Systems Research, Columbia University.

Inland floods and droughts are two more hazards that confront New York City. Climate models indicate that precipitation in New York City is likely to increase up to 5 percent by the 2020s and between 5 and 10 percent by the 2080s as seen in Figure 14 (NPCC 2010). These increases are projected to come in the form of more intense rain events. This means more days without precipitation between larger and more intense storms. As extreme rain events are expected to increase in intensity while decreasing in frequency, many of the rivers and tributaries that flow through New York City and feed into the bodies of water that surround the city may breech their banks more frequently as they will likely be unable to handle the volume of water flowing into them as runoff.

Droughts may also prove to be a hazard as a result of climate change if the period between rain events increases. A major concern is the New York City water supply, which is drawn from up to 100 miles north of the City. The higher levels of precipitation associated with climate change are expected to be offset by the greater rates of evaporation associated with temperature increase, thus increasing the likelihood of drought (NPCC 2010).

Vulnerability

The impacts of these climate hazards are interconnected and affect many systems in New York City differently but simultaneously. Roadways and subways, as well as ferry ports, industries located along the coast, and wastewater treatment facilities are susceptible to inundation. More hot days will increase electricity demand to run cooling systems, thereby increasing CO_2 emissions. The erosion of natural defenses like coastal wetlands increases the likelihood of flooding of nearby neighborhoods and industries.

Different populations are more vulnerable than others and these vulnerabilities are frequently differentiated along the lines of inland vs. proximity to coast, young vs. old, and rich vs. poor. One key climate change vulnerability is related to air quality and human health, since degradation of air quality is linked with warmer temperatures. The production of ozone (O_3) and particulate matter with diameters below 2.5 micrometers ($PM_{2.5}$) in the atmosphere is highly dependent on temperature (Rosenzweig and Solecki 2001). Therefore, increased temperatures are likely to make managing these pollutants more difficult. Both of these pollutants affect lung functioning with higher ozone levels being associated with increased hospital admissions for asthma. Further, the elderly and those suffering from heart and lung-related diseases have been shown to be more susceptible to the effects of heat, often resulting in death from heat stroke and heat -related causes (Knowlton et al. 2007).

New York City is vulnerable to heat waves and, as an archipelago, is particularly vulnerable to the effects of storm surge as a result of sea level rise. Projected sea level rise of 30 to 58 centimeters—or 104 to 140 centimeters, if rapid polar ice melt is considered—is not expected to inundate the city extensively; rather, the problem emerges when larger storms such as the 1-in-100 year storm, which are expected to become more frequent, produce a greater storm surge that will likely cause damaging floods (NPCC 2010).

Certain populations are more vulnerable to the effects of heat and higher sea levels. Approximately 967,022 people in New York City are 65 or older and of those it is estimated that 43 percent are living with some sort of disability (US Census Bureau 2008). These two factors contribute to the extreme vulnerability to heat of the elderly (Basu and Samet 2002). According to the Department of Health for the City of New York, during the heatwave of 2006 over half of those who died in New York City were over age 65 and all but five people were known to have suffered from some type of medical condition (Department of Health and Mental Hygiene [DOHMH] 2006).

New York City is a densely city with approximately 10,380 people in each of its 305 square miles or 790 square kilometers (Department of City Planning 2009). Within this area there are clear pockets of wealth and poverty. The majority of high per capita income households are concentrated along the eastern border of

Central Park with other areas of high per capita income households located along the western edge of the Park and the western shore along the southern part of Manhattan. The shore areas are primarily vulnerable to coastal flooding caused by the storm surge associated with the combined effects of an increased sea level and an extreme rain event.

The areas of low per capita income are in northern Manhattan, above Central Park, the borough of the Bronx and parts of Brooklyn. Sea level rise and coastal flooding are concerns for certain parts of these areas including Coney Island, Brighton Beach, and Jamaica Bay (See Figure 12). One of the more recurring vulnerabilities for these populations is extreme heat and the diminished air quality that accompanies the heating trend that New York City has seen over the last 100 years and that is projected to continue. The US Census Bureau has estimated that for the period 2005–2007 about twenty percent of those in New York City were living below the poverty line as established by the US Government (US Census Bureau 2008). During the heat wave of 2006, thirty-eight of those who died of heat stroke did not have a functioning air conditioning in their apartment (DOHMH 2006).

Adaptive Capacity

The environment in which New York City makes climate change adaptation and mitigation decisions is highly complex. Due to shared regional transportation, water, and energy systems, the stakeholders in any decision include numerous local governments, multiple state governments, businesses, and public authorities.

The foundation for tackling the challenges of climate change in New York City began in the mid-90s when the New York Academies of Science published, "*The Baked Apple? Metropolitan New York in the Greenhouse*" in 1996. Shortly thereafter, The Earth Institute at Columbia University, through the Center for Climate Systems Research (CCSR) released "*Climate Change and a Global City: The Potential Consequences of Climate Variability and Change*" (Rosenzweig and Solecki 2001). This report covered the Metro-East Coast Region and served as the first assessment of climate change and cities in the United States. In 2008, CCSR worked with the New York City Department of Environmental Protection to develop a sector specific climate assessment and action plan for New York City's water system (New York City Department of Environmental Protection 2008).

The New York City administration through its Office of Long-Term Planning and Sustainability created the NYC Climate Change Adaptation Task Force in 2008, which is now working with local experts, city departments and stakeholders to develop a comprehensive, integrated climate change risk assessment and adaptation plan for the critical infrastructure of the metropolitan region. The NYC Climate Change Adaptation Task Force is made up of representatives from over 30 city and regional departments and industries. The City administration also convened the New York Panel on Climate Change (NPCC) to provide expert information about climate change risks and adaptation. The NPCC is made up of climate change scientists, and experts from the legal field, insurance, telecommunications and transportation, and has provided the climate risk information needed to create actionable guidelines and plans for adapting the city's critical infrastructure for the projected effects of climate change (NPCC, 2010). The NPCC has also worked with the NYC Climate Change Adaptation Task Force to develop a common set of definitions for adaptation assessment.

The next step is to begin planning and making specific adaptation investments across the city. In the past in New York City, this has tended to be on a project basis and so has been less coordinated across sectors. Having brought decision-makers from all key departments in the city and from numerous sectors, the New York City climate change adaptation process is helping to facilitate more open avenues of communication and coordination within and among departments.

4.5 Across-City Findings

As the various scholars applied the risk framework to their cities, a combination of local factors revealed very specific climate risks confronting each city; however, there are some common threads as well (see Table 10). This summary table also provides the basis for developing a city climate risk assessment index. First, a multidimensional approach to risk assessment is essential as was observed in all four cities. Second, despite lack of data, climate risks can be articulated as especially demonstrated by the cases of Lagos and Delhi. Third, there are substantial mismatches between needs and responses—who mitigates, how much adaptation, and why, remain serious concerns. For instance Delhi, despite its extremely high risk due to its large vulnerable population is now focusing primarily on mitigation, as is Buenos Aires. Fourth, as observed in all cities vertical and horizontal fragmentation of urban governance is a challenge. As in the case of Delhi, however, such distributed jurisdictions may offer an opportunity. In Delhi, the Environment Ministry is an early adopter of pro-active climate change responses and is thus providing an entry point for systemic change. Finally, there are the oft-noted challenges for the climate scientists to provide credible, downscaled risk information on regionally crucial climate dynamics such as potential changes in the Indian Monsoon. We also found, however, that effective adaptation planning can start with the climate risk information available now. For a programmatic approach for risk assessment and adaptation planning where an institutional structure is articulated, see Table 11 (for additional details, see Mehrotra 2009).

TABLE 10
Risk-Response Summary of the Four Case Study Cities and the Kernels of a City Climate Risk Index

	Buenos Aires	Delhi	Lagos	New York City
Temperature observed trend and projections for 2050s	~2°C warming since 1900 (statistically significant at an alpha level of 0.05); 1°C to 1.5°C projected warming	Slight warming since 1900; 2006 0.2°C, lowest temp since 1935; 2007 44.9°C, highest recorded temp; 1.5°C to 2.5°C projected warming	About 1°C warming since 1900 (statistically significant at an alpha level of 0.05); Warmer period since 1990; 1°C to 2°C projected warming	Slight warming trend since 1900 (statistically significant at an alpha level of 0.05); 1.5°C to 3°C projected warming
Precipitation observed trend and projections for 2050s	22.8 millimeters per decade increase since 1900 (statistically significant at an alpha level of 0.05); projected change in precipitation uncertain: 0 to 15% increase	14 millimeters per decade increase since 1900 with large variability; projected change in precipitation uncertain: -15% to +35%	Slight decrease since 1900 with large variability; projected change in precipitation uncertain: -5% to 5%	17 millimeters per decade increase since 1900 with large variability (statistically significant at an alpha level of 0.05); projected change in precipitation uncertain: + 0 to 10%
Sea level rise observed trend and projections for 2050s	Since 1900 average water level of La Plata River increased 1.7 millimeters per year; since 1960 increased frequency of storms causing coastal flooding up to 2.8–5 m above mean sea level	Non-coastal city; experiences local flooding during monsoons	Oct 1992-Dec 1996 mean sea-level rise observed; Projected rise: 12 to 17 centimeters	3 centimeters per decade increase in mean sea level (statistically significant at an alpha level of 0.05); projected rise: 4 to 56 centimeters
Extreme events	Precipitation >100 mm/day increased from 19 times (1911–1970) to 32 times (1980–2000)	Extreme precipitation July 1994, July 1995, June 2003; extreme temperature May 1978, April 1988, May 1996; faces inland flooding due to intense precipitation during monsoons	Extreme precipitation May 1958, June 1962, July 1968, August 1998, November 1998; extreme temperature March 1988, March 1990, February 1998, March 1988, March 2001, March 2002, February 2003, March 2003, August 2004	Since 1900, seven of the ten years with most days over 32°C have occurred since 1980
Vulnerability				
Population	12 million (2001); ~10% of the Argentinean population	16 million; 500,000 added per year	18 million (2010); 600,000 added per year	8.2 million
Density	1.982/km^2	1,400/km^2	164/km2 to 60,204/ km^2	10,380/ km^2

TABLE 10, *continued*

	Buenos Aires	Delhi	Lagos	New York City
Percent poor or slum dwellers	~20% of the greater Buenos Aires agglom-eration	1.5 million live below poverty line; 45% live in unregulated settlements	70%; Lacks basic infrastructure	18.9% below poverty line defined by US Government
Percent of urban area (or population) susceptible to flooding	450,000 people live in flood-prone areas; 25% of city is flood-prone; annual flood damage to property estimated at US $30 million, projected to US $300 million by 2070	~7% (Delhi Disaster Management Authority) 3 million people live along Yamuna River prone to floods	Significant proportion of the city is located on land that is less than 5 meters above mean sea level; 1m of sea level rise will displace 3.6 million people	1% of New York City land area is less than three meters above mean sea level (Rosenzweig & Solecki, 2001)
City % of national GDP	~50%; US $245 billion (2005 PPP[1], Price Waterhouse Coopers, 2007 2); 2006 US $494.5 billion (2006 PPP, CIA World Fact Book); CABA ~24%; 2006 Geographic Gross Product ~US $50 billion; Service sectors is 80 percent of local economy	~3.3%, US $93 Billion (2005 PPP Price Waterhouse Coopers, 2007); US $2,812 billion (2006 PPP, CIA World Fact Book); >2% of 2007 GDP of India (2007 $27 Billion Gross State Domestic Product)	~10%; US $30 Billion (2005 PPP Price Waterhouse Coopers, 2007); US $299.5 billion (2006 PPP, CIA World Fact Book)]	~8.2%; US $1,133 billion (2005 PPP, Price Waterhouse Coopers, 2007); US $13,830 billion (2006 PPP, CIA World Fact Book)
Adaptive Capacity				
Institutions and governance measures affecting climate change actions[3]	CPI Country Ranking[4] 109; Score 2.9	CPI Country Ranking 85; Score 3.4; action oriented; fragmented jurisdictions	CPI Country Ranking 121; Score 2.7; fragmented jurisdictions; centralized decision making; local needs neglected	CPI Country Ranking 18; Score 7.3; Office of Long-term Planning and Sustainability provides coordination; multiple (>1,000) jurisdictions in metropolitan area
Willingness of City leadership to address climate change	Member C40 Large Cities Climate Leadership Group	Member C40 Large Cities Climate Leadership Group; People action for right to clean air; Supreme Court judgment requiring fuel switch in public transport; Government of Delhi steps up to challenge—world's largest fleet of CNG-operated public transport; introduction of BRTS, and Delhi Metro	Member C40 Large Cities Climate Leadership Group;	Member C40 Large Cities Climate Leadership Group; Host of second C40 Summit, 2007; Mayoral endorsement and active collabo-ration between city government and resident climate experts and institutions

TABLE 10, *continued*

	Buenos Aires	Delhi	Lagos	New York City
Information and resources compre-hensive analysis of climate risks for the city	Government supports range of research programs, such as National Program on Climate Scenarios, initiated in 2005; first and second national plans prepared in 1997 and 2006; third version under preparation.	National action plan on climate change prepared in June 2008, but Delhi-specific risk assessment lacking	Preliminary climate impact assessment (Ekanade et al., 2008) not linked to infrastructure investment; information on sea level rise not linked to action	Comprehensive Risk Information has been prepared by New York Panel on Climate Change (NPCC). NPCC has conducted in-depth climate risk analysis for infrastructure for NYC Climate Change Adaptation Task Force
Adminis-trative unit assigned to address climate change	In 2003 Climate Change Unit was established within the Ministry for Environ-mental and Sustainable Development; in 2007, this evolved into Climate Change Office.	Mitigation efforts led by the Ministry of Environment in close collaboration with Chief Minister of Delhi.	Lagos State Urban Renewal Authority (LASURA); World Bank.	Office of Long-term Planning and Sustain-ability established in September, 2006, and reports directly to Mayor
Balance between adaptation and mitigation	Mitigation >> Adaptation Dominated by mitigation efforts to reduce greenhouse gas emissions, neglect of adaptation despite high flood risk	Mitigation >> Adaptation Emphasis only on mitigation, (CDMs for landfills, electricity generation, bhagidari program for community participation, 1.7 million trees planted in 2007); adaptation needs neglected however implicit co-benefit from city greening for adaptation	Mitigation > Adaptation Primarily focused on mitigation like GHG emission reduction from solid waste, introduction of BRTS, a mass transit system, tree planting; adaptation not a focus, but co-benefits from other infrastructure investments	Mitigation = Adaptation City is proactively pursuing mitigation and adaptation responses
Risk	**Medium**	**High**	**Very High**	**Low**
	Climate Hazards: Sea-level rise and coastal flooding Vulnerability: Rapidly growing urban development with some encroachment onto the flood plain, lack adaptation planning and investments Adaptive capacity: lack of coordination and consistency in government initatives	***Climate Hazards:*** Heatwaves, inland flooding Vulnerbility: large population of poor lacking basic services and land tenure living in unregulated settlements, lack adaptation planning and investments Adaptive capacity: active civil society and judiciary, and leadership by Chief Minister of Delhi	***Climate Hazards***: Sea-level rise and coastal flooding Vulnerabiity: very large population of slum dwellers living in coastal areas prone to storm surge and flooding; lack of adaptiaton planning and investment Adaptive capacity: lack of dedicated institutional support for climate risk reduction	***Climate Hazards:*** Sea-level rise, coastal and inland flooding; heatwaves; Vulnerability: Resources, including insurance, available to plan and implement adaptations Adaptive capacity: Mayor actively leads efforts to address climate change with institutional support to the office of long-term planning

TABLE 10, *continued*

	Buenos Aires	Delhi	Lagos	New York City
Response				
	Conflicting plans, multiple jurisdictions reduce efficacy; lack of consistent, coordinated response; primary obstacles: lack of actionable climate information, vertical and horizontal fragmentation; divergent interests and responses	Mitigation is focus; lack of awareness about need for adaptation. Response is piecemeal because efforts are project-oriented. Incentives —subsidies and grants—have been effective for initiating projects, but operation and management remain neglected	Lagos State government is leading actor on climate change, which has been influenced by its membership in C40 Large Cities group; Initial studies of climate change risks but results have yet to inform ongoing and planned investments in infrastructure and slum upgrading	Climate Change Task Adaptation Task Force and its advisory body the New York City Panel on Climate Change are identifying mechanisms for leveraging planned and ongoing infrastructure investments to incorporate climate risk into decisions. PlaNYC set mitigation target of 30% reduction of CO2 emissions from 2005 levels by 2017

Source: Authors' analysis

[1]Purchasing power parity (PPP) is "[a] method of measuring the relative purchasing power of different countries' currencies over the same types of goods and services. Because goods and services may cost more in one country than in another, PPP allows us to make more accurate comparisons of standards of living across countries" (The World Bank Group 2009).

[2]*Source:* City Mayor Statistics, http://www.citymayors.com/statistics/richest-cities-2005.html

[3]Urban Governance Index is presently under development by UN-Habitat. Transparency International's country ranking of the National Corruption Perception Index (CPI) (2008) is used as a substitute for the purpose of illustration.

[4]Country ranking of the National Corruption Perception Index (CPI) where higher score implies less perceived corruption. The range of scores is between 1 and 10 andabout 180 countries are ranked in order of least corrupt to most. For details, see http://www.transparency.org/news_room/in_focus/2008/cpi2008/cpi_2008_table

TABLE 11
Institutional Structure for Risk Assessment and Adaptation Planning

Track	Objective	Output
1. Climate change and cities assessment for Mayors	To provide state-of-knowledge	Climate Change and Cities (2011) providing a global comprehensive assessment of risks, adaptation, mitigation options and policy implications
2. Across-city rapid risk assessment	To inform billions of dollars of ongoing urban investment that lack of climate risk considerations	Integrate climate risk assessment into City Development Strategies and pro-poor programs
3. City-specific, in-depth sectoral assessment	To redirect existing and planned investments)	Crafting city-specific risk and adaptation assessments for each city department, sector by sector
4. Learning from experience	To derive adaptation lessons from the early adopters	Detailed case-studies of implementation mechanisms from London, Mexico, New York City

Source: Mehrotra, 2009

5 LESSONS FOR DEVELOPING COUNTRIES AND KNOWLEDGE GAPS

Three initial lessons are summarized. ***First, a multidimensional approach to risk assessment is a prerequisite to effective urban development programs that incorporate climate change responses.*** At present most climate risk assessment is dominated by an over-emphasis on climate hazards. The application of the climate risk framework developed in this paper provides more nuanced and more actionable insights into the differential risks depending on the exposure to hazards on the spectrum of vulnerabilities of urban households, neighborhoods, and firms—for instance, from the most vulnerable slums in flood plains where infrastructure is lacking—and the adaptive capacity of local governments. However, a critical issue that requires further research is identifying when strategic retreat may be more cost-effective than adaptation and under what socio-economic conditions is it desirable and feasible.

Second, mismatches between needs and responses are occurring in regard to who should mitigate, how much to adapt, and why. Cities need climate change risk assessment in order to decide for themselves what is the right mix between mitigation and adaptation. Climate change risk frameworks, such as those described in this paper, can help cities to address the issue of mismatches, that is, the difference between a city's response to climate change as opposed to its actual needs. For example, it appears that some developing countries may be over-focusing on mitigation when they could be focusing more on adaptation due to the presence of critical climate risks in the near-term as well as in future decades. The seventeen largest economies account for most of the greenhouse gas emissions, the root cause of climate change (US Department of State 2009). And while many cities within these major economies have a significant role in mitigation, it may be prudent for cities in low-income countries with large populations of poor households to incorporate climate risk into ongoing and planned investments as a first step (Mehrotra 2009). However, since cities play an important role in greenhouse gas emissions in both developed and developing countries, there is also motivation for cities to lead on mitigation activities as well. Emissions from cities everywhere burden the environment, which is a global public good, and thus can be regulated through a combination of market and non-market incentives at the urban scale.

Third, the vertically and horizontally fragmented structure of urban governance is as much an opportunity as an obstacle to introducing responses to climate change. While much has been researched about the need for an integrated and coordinated approach, the fragmented governance structure of cities is unlikely to change in the short-term and offers the opportunity to have multiple agents of change. Examples in the case study cities show that early adopters on climate change solutions play an important role. The broad spectrum of governmental, civil society, and private sector actors in cities encourages a broader ownership of climate change adaptation programs.

Further, gaps and future research for scaled-down regional and local climate models were identified. In addition to the difficulties global climate models have with simulating the climate at regional scales, especially for locations with distinct elevational or land-sea contrasts, they also continue to have difficulty simulating monsoonal climates. Such is the case for climate projections for some of the case study cities in this paper, especially related to projected changes in precipitation. This is because simulation of seasonal periods of precipitation is challenging in terms of both timing and amount; in some cases the baseline values used for the projection of future changes are extreme—either too high or too low. Therefore, the percentage change calculated, vary greatly and can, on occasions, have distorted values. Especially for precipitation projections, the future trends may appear to be inconsistent compared to observed data, because the averages from the baseline period to which the projected changes were added onto are inaccurate, either due to a lack of data or extreme values within the time period that are skewing the averages. The inability of the global models to simulate the climate of individual cities raises the need for further research on regional climate modeling.

However, what is important to focus on in these future climate projections is the general trends of the projected changes and their ranges of uncertainty. These refer to attributes such as increasing, decreasing, or stable trends, and information about the uncertainty of projections in particular due to climate sensitivity or greenhouse gas emission pathways through time. Information on climate model projections regarding the extreme values and the central ranges both provide useful information to city decision-makers.

5.1 Concerns and Challenges Ahead

Even as the climate risk assessment framework explored in this paper is developed further and implemented, a multitude of concerns and questions arise regarding climate change challenges for cities, pointing the way towards further research and policy development. These include:

Ethical questions about what levels of government and what combination of stakeholders should (and in practice will) prioritize the actions on climate-related concerns where uncertainty at the local level remains high and the awareness among the poor and vulnerable sub-groups is low. How can cities address the specific needs of the most vulnerable sections of its inhabitants—the urban poor? Especially, as these sub-groups lack access to basic services and live in vulnerable shelters, and on disaster prone land—flood plains and the like—further environmental stress can be catastrophic for the slum dwellers.

How can mega-cities in developing countries do a holistic assessment of the potential risk due to climate change, plan complementary mitigation strategies and adaptive resilience that do not remain mere recommendations in reports but lead to action? The lack of a climate change strategy for the city increases the risk of the already vulnerable urban poor—how can this neglect of the poor be addressed in the broader climate and city debate? As Delhi has introduced CNG-fueled public transportation as a mitigation measure, what are the strategic interventions—short-gestation, low-cost, high-impact—that facilitate large-scale adaptation to reduce the economic, social, and environmental risk to cities, particularly for the poor?

How can city infrastructure—public transport, water, electricity—and social institutions for public health or disaster management be retrofitted to adapt to climate change? How can a city craft a flexible and calibrated approach towards adaptive resilience?

How can cities develop an institutional response to climate change with complementary strategies for mitigation and adaptation that result in action on the ground? What strategies work for vertical coordination among national, regional, and local policy efforts? How can horizontal co-operation be fostered resulting in collaborative action across stakeholders and between departments and agencies at the city level, and across cities—nationally and internationally?

References

Abosede, F. 2006. "Housing in Lagos Mega City—Improving Livability, Inclusion and Governance." Paper presented at the Social and Economic Rights Action Center's (SERAC) International Conference, "Building Nigeria's Capacity to Implement Economic, Social and Cultural Rights: Lessons Learned, Challenges and the Way Forward," Abuja, Nigeria, September 27–28, 2006.

Abosede, F. A. 2008. "The Challenges of Slum Upgrading—The Lagos Experience." Paper presented at the International Policy Dialogue: "The challenges of slum upgrade: sharing Sao Paulos's experience," Sao Paulo, Brazil, March 10–14, 2008.

Aggarwal, D., and M. Lal. 2001. Vulnerability of Indian Coastline to Sea Level Rise. New Delhi, India: Centre for Atmospheric Sciences, Indian Institute of Technology.

Assessments of Impacts and Adaptations to Climate Change. 2005. Informe final del proyecto LA 26 [LA 26 project, final report assessment]. www-atmo.at.fcen.uba.ar/~lcr/libros/Cambio_Climatico-Texto.pdf [Accessed January 25, 2009].

Awosika, L. F., French, G. T., Nicholls, R. J., and C.E. Ibe. 1992. The impact of sea level rise on the coastline of Nigeria. Proceedings from IPCC Symposium: The Rising Challenges of the Sea. Magarita, Venezuela. March 14–19, 1992.

________. 1993a. "Impacts of sea level rise on Nigeria," Proceedings from IPCC Symposium "The Rising Challenge of the Sea," Margarita, Venezuela. March 14–19, 1992.

Awosika, L. F., Ojo O., andT.A.Ajayi et al. 1993b. "Implications of Climate Changes and Sea Level Rise on the Niger Delta, Nigeria phase 1 Report." UNEP, Nairobi, Kenya.

Barros, V., Menéndez A., Natenzon C., Kokot R., Codignotto J., and M. Re et al. 2005. "Climate Change Vulnerability to Floods in the Metropolitan Region of Buenos Aires City." Paper presented at the Assessments of Impacts and Adaptations to Climate Change (AIACC) Workshop, "Climate Change," Bellagio, May 7–12. http://www.aiaccproject.org/working_papers/working_papers.html. [Accessed January 25, 2009].

Barros, V., Menéndez A., Natenzon C., Kokot R., Codignotto J., and M. Re et al. 2008. "Storm Surges, Rising Seas and Flood Risks in Metropolitan Buenos Aires." In Climate Change and Vulnerability, ed. Neil Leary et al. , 117–133. London, UK: Earthscan.

Basu R., and J.M. Samet. 2002. "Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence." Epidemiologic Reviews 24: 190–202.

Baumert, K., Herzog T., and J. Pershing. 2005. Navigating the Numbers: Greenhouse Gas Data and International Climate Policy. Washington DC: World Resources Institute.

Bradley, R., Staley B., Herzog T., Pershing J., and K. Baumert. 2007. Slicing the Pie: Sector-based Approaches to International Climate Agreements. Washington DC: World Resource Institute.

Brandon, C., and K. Hommann. 1995. The Cost of Inaction: Valuing the Economy–Wide Cost of Environmental Degradation in India. Washington, DC: World Bank.

Bureau of Economic Analysis. 2008. "GDP by Metropolitan for 2006 and Revised 2004–2005." News Release. http://www.bea.gov/newsreleases/regional/gdp_metro/gdp_metro_newsrelease.htm. [Accessed January 25, 2009].

Camillioni, I., and V. Barros. 2008. "Climate." In Environmental Atlas of Buenos Aires. http://www.atlasdebuenosaires.gov.ar/aaba/index.php?option=com_content&task=view&id=339&Itemid=188&lang=en Retrieved January 24, 2009. [Accessed January 25, 2009].

Carmin, J., and D. Roberts. 2009. "Government Institutions and Innovations in Governance for Achieving Climate Adaptation in Cities." Fifth Urban Research Symposium. Marselles, France. June, 2009.

Cropper, M. L., Simon N. B., Alberini A., and P.K. Sharma. 1997."The health effects of air pollution in Delhi, India." Policy Research Working Paper 1860, World Bank. http://ssrn.com/abstract=604994.

Clichevsky, N. 2002. Pobreza y políticas urbano-ambientales en Argentina (Poverty and urban-environmental policies in Argentina). Santiago de Chile: CEPAL- ECLAC, División de Medio Ambiente y Asentamientos Humanos.

Defensoría del Pueblo de la Ciudad de Buenos Aires. 2006. Informe de situación. Desalojos de "Nuevos Asentamientos Urbanos" (Situation report. Eviction of "New urban settlements"). http://www.defensoria.org.ar/institucional/doc/asentamientos.doc. [Accessed January 25, 2009

Delhi. 2009. In Encyclopædia Britannica. Encyclopædia Britannica Online: http://www.britannica.com/EBchecked/topic/156501/Delhi. [Accessed June 02, 2009].

Department of City Planning. 2009. New York City: Department of City Planning. http://www.nyc.gov/html/dcp/. [Accessed January 15, 2009].

Department of Environment. 2008. *Delhi, amongst the Greenest Capitals of the World.* New Delhi, India: Department of Environment, Government of National Capital Territory of Delhi.

Department of Health and Mental Hygiene. 2006. *DOHMH Vital Signs: 2006 Heat Wave Investigation Report.* www.nyc.gov/html/doh/downloads/pdf/survey/survey-2006heatdeaths.pdf - 2006-11-15

Department of Planning. 2008. *Economic Survey of Delhi 2007–08.* New Delhi: The Government of the National Capital Territory of Delhi, Government of India. http://www.delhi.gov.in/wps/wcm/connect/doit_planning/Planning/Economic+Survey+of+Dehli/. [Accessed January 05, 2009].

Delhi Development Authority. 2005. *Master Plan for Delhi, 2021.* New Delhi, India: Development Authority, Government of National Capital Territory of Delhi, Government of India. http://www.dda.org.in/planning/draft_master_plans.htm. [Accessed January 05, 2009].

Directorate for Statistics and Census. 2007. Anuario estadístico 2006 [Statistical yearbook 2006]. Gobierno de la Ciudad de Buenos Aires, Ministerio de Hacienda. http://buenosaires.gov.ar/areas/hacienda/sis_estadistico/anuario_2006/ cap_11.htm. [Accessed January 25, 2009].

Douglas, I., and Alam, K. 2006. *Climate change, Urban Flooding and the Rights of the Urban Poor in Africa: Key Findings from Six African Cities.* London, UK: ActionAid International. http://www.actionaid.org.uk/doc_lib/urban_flooding_africa_report.pdf

Ekanade O., Ayanlade A., and I.O.O. Orimogunje. 2008. Geospatial Analysis of Potential Impacts of Climate Change on Coastal Urban Settlements in Nigeria for the 21st Century." *Journal of Geography and Regional Planning,* 1 (3): 49–57.

Falczuk, B. 2008. "Surface Water." In *Environmental Atlas of Buenos Aires.* http://www.atlasdebuenosaires.gov.ar/aaba/index.php?option=com_content&task=view&id=339&Itemid=188&lang=en. [Accessed January 24, 2009].

Federal Republic of Nigeria. 2006. *Report of the Presidential Committee on Redevelopment of Lagos Mega-City Region*. Lagos: Lagos Megacity Project.

Folorunsho, R., and L.F. Awosika. 1995. "Nigerian Meteorological Induced Changes along the Nigerian Coastal Zone and Implications for Integrated Coastal Zone Management Plan." Proceedings from BORDOMER '95 International Convention "Rational Use of Coastal Zone," Bordeaux, France, February 6–10, 1995.

French, G.T., Awosika L.F., and C.E. Ibe. 1995. "Sea Level Rise and Nigeria: Potential Impacts and Consequences." *Journal of Coastal Research* 14: 224–42.

González, Silvia. 2005. *Ciudad visible vs. ciudad invisible: la gestión del riesgo por inundaciones en la Ciudad de Buenos Aires*. en *Territorios* 13: 53–67.

Government of India. 2002. *Climate Change and India.* New Delhi, India: Government of India. http://envfor.nic.in/cc/index.htm. [Accessed January 12, 2009].

______. (2008). National *Action Plan for Climate Change*. New Delhi, India: Government of India.

Hallegatte, S., Henriet F., and J. Corfee-Morlot. 2008. "The Economics of Climate Change Impacts and Policy Benefits at City Scale: A Conceptual Framework." Environment Working Paper 4, Environment Directorate, Organisation for Economic Co-operation and Development: Paris, France.

Hoornweg, D., Ruiz Nuñez F, Freire M., Palugyai N., Villaveces M., and Wills Herrera E. 2007. "City Indicators: Now to Nanjing." Paper presented at the Third World Urban Forum. Vancouver, Canada. June 22, 2006.

Hunt, A., and P. Watkiss. 2007. *Literature Review on Climate Change Impacts on Urban City Centres: Initial Findings*. (ENV/EPOC/GSP(2007)10). Paris: Environment Directorate, Organisation for Economic Co-operation and Development.

Instituto Nacional de Estadística y Censos. 2003. *Qué es el Gran Buenos Aires? (What is Greater Buenos Aires?)*. http://www.indec.gov.ar/glosario/folletoGBA.pdf . [Accessed January 25, 2009].

IPCC. 2001a. "Special Report on Emissions Scenarios." A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, ed. Nakicenovic N., Alcamo J., Davis G., de Vries B., Fenhann J., Gaffin S. et al. Cambridge University Press, Cambridge, UK.

———. 2001b. "Climate Change 2001." Working Group II: Impacts, Adaptation and Vulnerability Assessment Report, Intergovernmental Panel on Climate Change.

———. 2007a. "Climate Change 2007: The Physical Science Basis." Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B. et al. Cambridge University Press, Cambridge and New York.

———. 2007b. "Climate Change 2007: Impacts, Adaptation and Vulnerability." Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J., and Hanson, C.E. Cambridge University Press, Cambridge, UK.

———. 2007c. "Climate Change 2007: Mitigation." Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. Metz B., Davidson O.R., Bosch P.R., Dave R., and Meyer L.A. Cambridge University Press, Cambridge and New York.

———. 2007d. "Climate Change 2007: Synthesis Report." Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. (Core Writing Team) Pachauri R.K and Reisinger A. IPCC, Geneva, Switzerland.

Iwugo, O.K., D'Arcy B., and Anoch R. 2003. "Aspects of Land Based Pollution of an African Coastal Megacity oof Lagos." Paper presented at the International Water Association International Conference, "Diffuse Pollution and Basin Management," Dublin, Ireland. August 17–22, 2003.

Kinney, P. L., O'Neill M.S., Bell M.L., and J. Schwartz. 2008. Approaches for Estimating Effects of Climate Change on Heat-Related Deaths: Challenges and Opportunities." *Environmental Science and Policy* 11: 87–96.

Knowlton, K., Barry L., Richard A. G., Rosenzweig C., Hogrefe C., Rosenthal J. K., and P.L. Kinney. 2007. "Projecting Heat-Related Mortality Impacts under a Changing Climate in the New York City Region." *American Journal of Public Health* 97 (11): 2028–34. ABI/INFORM Global database. [Accessed January 31, 2009].

Mehrotra, S, et al. (2011). Climate Risk, Disasters, and Cities, in C. Rosenzweig, W. Solecki, S. Hammer, and S. Mehrotra (Eds.). *Climate Change and Cities (ARC3)*, London: Cambridge University Press, 2011.

Mehrotra, S. (Forthcoming). *Advanced Framework for Urban Climate Risk Assessment.* New York: The New School.

Mehrotra, S. 2009. Climate and Cities: Crafting a Global Institutional Structure for Risk Assessment and Adaptation Planning. White paper. New York: Columbia University, and NASA Goddard Institute of Space Studies.

______. 2003. "Unfinished Promise: Institutionalizing Local Knowledge for Risk Reduction in Earthquake-Prone Settlements of the Poor: Porbandar District, Gujarat, India." ProVention Consortium, Applied Research Grant proposal. Washington, DC: World Bank.

Menéndez, A., ed. 2005. Componente B1, Vulnerabilidad de la Zona Costera [B1 Component, Vulnerability of the Coastal Zone]. In Cambio Climático: Segunda Comunicación Nacional Gobierno de la República Argentina Informe final. Fundación Di Tella, Fundación Bariloche, Global Environment Facility, World Bank.

Morka, C. F. 2007. "A Place to Live: A Case Study of the Ijora-Badia Community in Lagos, Nigeria." In Global Report on Human Settlements 2007: Enhancing Urban Safety and Security. http://www.unhabitat.org/grhs/2007.

Murgida, A. M., and S.G. González. 2005. "Social Risk, Climate Change and Human Security: An Introductory Case Study in Metropolitan Area of Buenos Aires (Argentina). Proceedings from an International Workshop "Human Security and Climate Change," Oslo, Norway. June 21–23, 2005.

Murgida, A. 2007. Informe Final: Amenazas-Vulnerabilidad- Adaptación Y Mitigación, Ciudad Autónoma De Buenos Aires [Final Report Assessment: Threats-Vulnerability-Adaptation and Mitigation, Autonomous City of Buenos Aires]. Buenos Aires: Oficina de Protección Climática y Eficiencia Energética. GCABA, mimeo.

Murgida, A.M., and C.E. Natenzon. 2007. "Social 'Downscaling': A Few Reflections on Adaptation in Urban Environments." Proceedings from III Regional Conference "Global Changes — Round Table 4 — Urban Aspects," Sao Paulo, Brazil, November 4–8, 2007.

Natenzon, C., and J.M. Viand. 2008. *Gestión de los Desastres en Argentina. Instituciones Nacionales involucradas en la Problemática de las Inundaciones* [Disaster Management in Argentina. National Institutions involved in the Flooding Problem]. In *América Latina: sociedade e meio ambiente* ed. A.I. Geraiges de Lemos, J.L. Sanches Ross and A. Luchiari, 171–85 . Sao Paulo, Brazil: Expressão Popular.

New York City Department of Environmental Protection. 2008. *The Assessment and Action Plan: A Report Based on the Ongoing Work of the DEP Climate Change Task Force.* New York: The New York City Department of Environmental Protection.

New York City Panel on Climate Change (NPCC). 2010. "Climate Change Adaptation in New York City: Building a Risk Management Response." Ed. C. Rosenzweig and W. Solecki. Prepared for use by the New York City Climate Change Adaptation Task Force. Annals of the New York Academy of Science, 2010. New York.

Nubi T.O., and Omirin M.M. 2006. "Urban Violence, Land Rights and the Environment." Paper presented at the International Conference "Environmental Economics and Conflict Resolution," Lagos, Nigeria. 2006.

NYSE Euronext. 2009. *NYSE Euronext*. http://www.nyse.com/about/listed/1170350259411.html. [Accessed June 9, 2009].

Ogun State Government. 2005. *Ogun State Regional Plan 2005–2025: Development Pressure Area-DPA Report*.

Parsons, E. A., Burkett V.R., Fisher-Vanden K., Keith D.W., Mearns L.O., and H.M. Pitcher. 2007. "Global-Change Scenarios: their Development and Use." Sub-report 2.1b of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Office of Biological & Environmental Research, Department of Energy, Washington DC.

Pírez, P. 2002. "Buenos Aires: Fragmentation and Privatization of the Metropolitan City." *Environment and Urbanization*, 14 (1): 58–76.

______. 2008. "Planning." In *Environmental Atlas of Buenos Aires*. http://www.atlasde-buenosaires.gov.ar/aaba/index.php?option=com_content&task=view&id=34&Itemid=30&lang=en. [Accessed January 28, 2009].

Pochat, V., Natenzon C. E., and A. Murgida. 2006. "Domestic Policy Frameworks on Adaptation to Climate Change in Water Resources. Argentina Country Case Study." In *Working Together to Respond to Climate Change: Annex I, Expert Group Seminar,* UNFCCC/ OECD Global Forum on Sustainable Development, Paris, France, March 27–28. http://www.oecd.org/dataoecd/29/2/36448827.pdf.

Rawls, J. 1971. *A Theory of Justice*. London, UK: Oxford University Press.

Revi, A. 2007. "Climate Change Risk: An Adaptation And Mitigation Agenda For Indian Cities." India Background Paper for Global Urban Summit. Bellagio, July, 2007.

Ríos, D., and S. González. 2005. La aglomeración gran Buenos Aires [The greater Buenos Aires agglomeration]. In: *Cambio Climático, Segunda Comunicación Nacional. Gobierno de la República Argentina. Informe final.* Gobierno de la República Argentina Informe final. Fundación Di Tella, Fundación Bariloche, Global Environment Facility, World Bank.

Rosenzweig, C., Solecki, W., Hammer, S., Mehrotra, S. (Eds.). (2011). *Climate Change and Cities.* London: Cambridge University Press.

Rosenzweig, C. and W.D. Solecki, eds. 2001. Climate Change and a Global City: The Potential Consequences of Climate Variability and Change—Metro East Coast." Report for the U.S. Global Change Research Program, *National Assessment of the Potential Consequences of Climate Variability and Change for the United States*. New York: Earth Institute at Columbia University.

Rosenzweig, C., and D. Hillel. 2008. *Climate Variability and the Global Harvest: Impact of El Niño and Other Oscillations on Agro-Ecosystems*. New York: Oxford University Press.

Satterthwaite, D., Huq S., Pelling M., Reid H., and P. Lankao-Romero. 2007. *Adapting to Climate Change in Urban Areas: The Possibilities and Constraints in Low- and Middle-Income Nations*. Climate Change and Cities Series, Discussion Paper 1. London, UK: International Institute for Environment and Development (IIED).

Sen, A. 1999. *Development as Freedom*. New York: Anchor Books.

Stern, N. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press.

Shook, G. 1997. "An Assessment of Disaster Risk and its Management in Thailand." *Disasters 21* (1): 77–88.

The City of New York. 2007. *PlaNYC: A Greener Greater New York*. New York: The City of New York. http://www.nyc.gov/html/planyc2030/html/downloads/the-plan.shtml.

______. 2009. *Financial Plan, Summary: Fiscal Years 2009–2013.* New York, USA: Office of Management and Budget, May 1. http://www.nyc.gov/html/omb/html/publications/finplan05_09.shtml. [Accessed June 9, 2009].

UK Climate Impacts Programme. 2009. http://www.ukcip.org.uk/index.php

UNDP (United Nations Development Programme). 2004. Human development report. www.hdr.undp.org

UN-Habitat. 2003. Slums of the World: The Face of Urban Poverty in the New Millennium? Nairobi, Kenya: Global Urban Observatory, UN-Habitat.

______. 2004. State of the Lagos Mega City and other Nigerian Cities Report. Lagos, Nigeria: UN-Habitat and Lagos State Government.

______. 2006. "A Tale of Two Cities." In World Urban Forum III, An International UN-Habitat Event: Urban Sustainability. Vancouver, Canada. June 19–23, 2006.

______. 2008a. The State of World's Cities 2008/2009: Harmonious Cities. London, UK: Earthscan.

______. 2008b. The State of African Cities 2008: Framework for Addressing Urban Challenges In Africa. Nairobi, Kenya: UN-Habitat.

US Census Bureau. 2008. State and County QuickFacts. http://quickfacts.census.gov/qfd/states/36/3651000.html. [Accessed January 25, 2009].

US Department of State. 2009. Major Economies Forum on Energy Security and Climate Change. http://www.state.gov/g/oes/climate/mem/#.

World Bank. 2009. Glossary. http://youthink.worldbank.org/glossary.php#ppp. [Accessed June 9, 2009].

PART 2

Infrastructure, the Built Environment and Energy Efficiency

CHAPTER 7

Getting to Carbon Neutral: A Review of Best Practices in Infrastructure Strategy

C. Kennedy,* D. Bristow, S. Derrible, E. Mohareb, S. Saneinejad, R.Stupka, L. Sugar, R. Zizzo, and B. McIntyre

Summary: Measures of cost-effectiveness for reducing GHG emissions from cities are established for 22 case studies, mainly involving changes to infrastructure. GHG emissions from cities are primarily related to transportation, energy use in buildings, electricity supply, and waste. A variety of strategies for reducing emissions are examined through case studies ranging from US$0.015 million to US$460 million of capital investment (US dollars). The case studies have been collected to support a Guide for Canadian Municipalities on Getting to Carbon Neutral (G2CN). The cost effectiveness, given by annual GHG emissions saved per dollars of capital investment, is found to vary between 3 and 2,780 t e CO_2 / yr / US$million for the G2CN database. The average cost-effectiveness of the database of 550 t e CO_2 / yr / US$million is significantly exceeded by solid waste projects in Canada (FCM); and by developing world projects under the Clean Development Mechanism (CDM). Five case studies in the G2CN database with GHG savings over 100,000 t eCO_2 are highlighted. Yet, cities need to start planning projects with reductions of the order 1 million plus t eCO_2 per year in order to substantially reduce emissions below current levels for smaller cities (1 million people) and mega-cities.

*Corresponding author: christopher.kennedy@utoronto.ca

1. INTRODUCTION

The main sources of greenhouse gas (GHG) emissions attributable to cities are transportation, energy use in buildings, electricity supply, and to a lesser extent waste (Kennedy et al. 2009). Transportation emissions per capita are inversely related to urban density; sprawling, low density cities designed around automobiles have higher emissions than more compact cities with substantial public transportation. Building energy use is primarily dependent on climate, i.e., heating degree days, but can also be impacted by the quality of building envelopes. Emissions from electricity depend to some extent on the level of consumption, but more significant is the means of power generation; nuclear and renewable sources (hydro, solar, wind, etc.) have close to zero direct emissions. Emissions from landfill waste, which are often particularly significant for cities in the developing world, are primarily dependent on the extent to which waste methane or other gases are captured. Overall, it is clear that urban GHG emissions are highly dependent on a range of infrastructure systems.

In order to reduce GHG emissions, it is necessary to first understand the scale of such emissions. Inventories of emissions primarily from western cities typically vary from about 3 t eCO_2 per capita to over 20 t e CO_2 per capita (Kennedy et al. 2009). This means that for mega-cities of close to 10 million people, GHG emission are of the order 100 million t e CO_2. For example, Los Angeles County has estimated emissions of 122 million t e CO_2; and New York City has emissions of 85 million t e CO_2 (Table 1). Smaller western cities, of 1 million people, typically have emission of the order 10 million t e CO_2.

TABLE 1
Total GHG Emissions from Ten Global Urban Regions (adapted from Kennedy et al. 2009)

Urban Region	Year	Population	GHG Emissions (million t e CO_2 /yr.)
Los Angeles County	2000	9,519,338	122.0
New York City	2005	8,170,000	85.3
Greater London Area	2003	7,364,100	70.6
Greater Toronto Area	2005	5,555,912	63.4
Bangkok (City)	2005	5,658,953	60.1
Cape Town (City)	2005	3,497,097	40.1
Denver (City & County)	2005	579,744	12.3
Greater Prague Region	2005	1,181,610	11.0
Barcelona (City)	2006	1,605,602	6.7
Geneva (Canton)	2005	432,058	3.3

Many different infrastructure strategies can be employed in reducing GHG emissions from cities. Table 2 displays a range of strategies under categories of transportation/land-use, buildings, energy supply, solid waste, water/wastewater and carbon sequestration. Most of these strategies entail changes to infrastructure or built form, but a few economic strategies, e.g., congestion pricing, are also considered. The strategies are also classified in terms of their scale of engagement. Those strategies with higher scales of engagement generally entail higher investments and produce higher GHG reductions (relative to strategies in the same row). The designation of scale of engagement in Table 2 is essentially a preliminary hypothesis for this research, though based on 10 years of research and teaching on sustainable urban infrastructure. Clearly, the GHG reductions achieved through building a subway or a concentrating solar plant are much higher than those from a bicycle lane, or a vertical axis wind-turbine. The aim of the authors is to quantify this scale of engagement more rigorously.

Amongst the strategies in Table 2 are some that reduce GHG emissions through increased energy efficiency and others that use carbon free technologies. Strategies such as high occupancy vehicle lanes, bus rapid transit, green roofs and improved building operations make more efficient use of energy, but in absence of other strategies still entail GHG emissions; these are examples of low carbon alternatives. Other strategies, such as pedestrianization, photovoltaics, wind turbines and concentrating solar generation, eliminate direct GHG emissions. Further, strategies in Table 2 can also be emissions free, depending on conditions. For example, a carbon free electricity supply will enable the use of light rail transit, subways, electric vehicles and ground source heat pumps that have no GHG emissions. Employing strategies that use fossil fuel energy more efficiently help cities *approach* carbon neutral, but to reach carbon neutrality will substantially require carbon free technologies.

TABLE 2
Preliminary Classification of GHG Reduction Strategies by Scale of Engagement

Scale of Engagement

Category	Minor	Medium	Major
Transportation/ Land-use	High occupancy vehicle lanes; smart commute; car-pool networks; car share Natural gas vehicles (e.g. municipal buses) Bus rapid transit On-road bike lanes Bike share	Financial penalties to auto use (e.g., tolls, congestion charging) Incentives for use of low-emission vehicles. Light rail transit Segregated bike lanes	Pedestrianization of city centres Infrastructure for plug-in-hybrid electric vehicles Subways Bicycle highways
Buildings	Building energy retrofits Green roofs Energy star buildings	Improved building operations Photovoltaics Solar water/ air heaters Ground source heat pumps	Demolition and reconstruction with high energy efficiency green buildings
Energy	Vertical axis wind turbines	District energy systems Borehole or aquifer thermal storage	Nuclear power plants Concentrating solar generation
Solid Waste	Landfill methane capture Vacuum collection of solid waste	Solid waste gasification	Increased recycling Greening supply chains
Water/ Wastewater	Reduced demand through low-flush toilets or low-flow shower heads	Reduced demand through grey-water systems	Anaerobic waste water treatment plants
Carbon Sequestration	Planting of urban forestry Algae	Residential scale urban agriculture in CO_2-enriched greenhouses	Industrial scale urban agriculture in CO_2 -enriched greenhouses Carbon offsets

Note: the seventh category, integrated community design, cuts across the six categories shown.
Source: Kennedy and Mohareb 2009

2. OBJECTIVES OF THE PAPER

The specific objectives of this paper are to:

i) Identify which infrastructure strategies can lead to the greatest reductions in GHG emissions from cities, in both developed and developing nations.

ii) Identify which infrastructure strategies are most cost-effective in reducing GHG emissions (i.e., quantify reductions in t CO2 equiv. per dollar investment)

The objectives are addressed by collecting data from approximately 70 case studies of best practices in carbon neutral urban design. This review of case studies is the first phase of a larger project, described in section 3, which aims to produce a Guide for Canadian Municipalities on *Getting to Carbon Neutral* (G2CN). The results of the case studies show projects ranging from USUS$ 0.015 million to US US$460 million of investment, with GHG savings between 45 t e CO_2 and 950,000 t e CO_2. Findings from the data set are compared to those from two other sources: projects under the Federation of Canadian Municipalities *Green Municipal Fund*; and those funded under the United Nations *Clean Development Mechanism*. Caveats to the case study approach are included in the discussion.

3. BACKGROUND: GETTING TO CARBON NEUTRAL

As part of the Toronto Region's Living City initiative (TRCA 2008), the Sustainable Urban Infrastructure Group at the University of Toronto is producing a guidebook to assist medium to large Canadian municipalities down the path to becoming carbon neutral (Kennedy 2009). As per the analysis undertaken for this guidebook under the G2CN project, the authors define carbon neutrality to require that direct and indirect emissions from the municipality minus sequestered carbon and offsets sum to zero, a definition that has been extended to this paper as well. *Getting to* carbon neutral state will first entail developing low carbon cities.

As a first step to addressing climate change many cities have established inventories of GHG emissions, often using the simple, pragmatic approach of ICLEI[1]. Within Canada, 157 municipalities are participating in the Partners for Climate

[1]See International Local Government GHG Emissions Analysis Protocol Draft Release Version 1.0.: http://www.iclei.org/fileadmin/user_upload/documents/Global/Progams/GHG/LGGHGEmissionsProtocol.pdf Accessed May 2009.

Protection (PCP) program. Most of these municipalities have established inventories of GHG emissions, but many are struggling, however, to develop and implement strategies for substantially reducing GHGs.

Yet there are many examples of sustainable design practices both in Canada and elsewhere that have lead to lower GHG emissions for various neighbourhoods or infrastructure systems within cities[2]. Many of the strategies employed for these are substantial, long-term endeavours requiring serious investment and some degree of societal change. They demonstrate that if municipalities were to aggressively pursue a wide-range of GHG emissions reducing strategies, subject to their own unique conditions, it may be technically feasible for many of them to become carbon neutral.

The first phase of the G2CN (Getting To Carbon Neutral) project entails collecting and analyzing best case practices and strategies in sustainable urban design and planning. The review includes case studies in areas of transportation, buildings, energy systems, waste management, water infrastructure, carbon sequestration and integrated community design. The case studies are discussed further below.

The second stage involves developing best practice strategies for reducing municipal GHG emissions in the categories of buildings, transportation/land-use, energy supply, municipal services and carbon sequestration/offsets (Table 3). For each strategy the guide provides simple, generic rules of thumb for approximately quantifying the reductions in GHG emissions that can be achieved. The formulae can be used, for example, to estimate GHG reductions from installing X km of light-rail; constructing a gasification plant to process Y tonnes of solid waste; or servicing Z% of homes in a municipality using a district energy scheme[3]. The rules of thumb typically calculate changes to intermediary quantities, such as energy use and vehicle kilometres travelled, from which GHG emissions are subsequently determined. The guide does not seek to be prescriptive in how the GHG reduction strategies are selected; it offers a menu of choices.

---

[2] Canadian examples include: Calgary's wind-powered C-train, Toronto's deep-lake water cooling, and sustainable neighbourhood developments at Dockside Green (Victoria), South East False Creek (Vancouver), and Okotoks (nr. Calgary). To these, international examples such as Malmo's port, Hammarby (Stockholm) and Kronsberg (Hannover) can be added. A few western cities such as London, UK, and Freiburg, Germany, have reduced per capita automobile use and associated emissions. Currently under development are communities such as Masdar, near Abu Dhabi, and Dongtan, near Shanghai, which aim to be the world's first carbon neutral sustainable cities.

[3] An example rule of thumb is that retrofitting of residential homes typically reduces average energy demand by 20 to 25% in Canada.

Table 3. Strategies for Reducing Municipal Greenhouse Gas Emissions

BUILDINGS Strategy 1: Reduce Energy Demand Strategy 2: Utilize Solar Energy Strategy 3: Ground Source Heat Pumps
TRANSPORTATION / LAND USE Strategy 1: Appropriate Land Use Strategy 2: Public Transportation Strategy 3: Active Transportation Strategy 4: Deter Automobile Use Strategy 5: Changing Vehicle Technology
ENERGY SUPPLY Strategy 1: Electricity from Renewable Sources Strategy 2: Aquifer and Borehole Energy Storage Strategy 3: District Heating and Cooling Strategy 4: Combined Heat and Power
WASTE, WATER & MUNICIPAL SERVICES Strategy 1: Increased Recycling Strategy 2: Waste Incineration & Gasification Strategy 3: Methane Capture Strategy 4: Water Demand Management
CARBON SEQUESTRATION and OFFSETS Strategy 1: Urban Agriculture & CO_2-enriched Greenhouses Strategy 2: Urban Forestry Strategy 3: Geological & Mechanical Sequestration

Source: Kennedy 2009

4. METHODOLOGY

In this paper, data from the case studies assessed in the G2CN guide is used to estimate the cost effectiveness of GHG emissions savings initiatives. Cost effectiveness has been defined as follows:

$$\text{Cost effectiveness} = \frac{\text{Annual GHG emissions saved}}{\text{Capital investment}}$$

The above measure only considers initial capital costs; it excludes recurring costs, user fees, financial benefits, low-cost financing and/or government subsidies. Given this, cost effectiveness may be considered as a limited economic measure since it gives no indication of financial returns. However, it is useful from the perspective of capital budgeting to reduce GHG emissions.

The case study selection procedure sought to establish leading edge examples of initiatives being taken by municipalities, cities or regions to reduce GHG emissions, both in Canada and worldwide. Extensive teaching and research experience on a wide range of sustainable urban design topics, including green buildings (Zachariah et al. 2002; Dong et al. 2005; Saiz et al. 2006), urban water systems (Sahely and Kennedy 2007; Racoviceanu et al. 2007), sustainable urban transportation (Kennedy 2002; Kennedy et al. 2005), alternative energy systems (Kikuchi et al. 2009), sustainable neighborhoods (Engel-Yan et al. 2005; Codoban and Kennedy 2008) and urban metabolism (Sahely et al. 2003; Kennedy et al. 2007), and the application of the principles of industrial ecology to the design of sustainable cities (Kennedy 2007), provided an initial background to the selection of the case studies.

For each case study, the aim was to establish a database on costs, benefits, barriers to implementation, and GHG savings. The case studies, thus, also provided empirical data to support/verify the *rules of thumb* developed in the above-mentioned *Guide*. The purpose of this paper is to use the data from the case studies to examine the cost effectiveness of strategies for reducing emissions. In this context, the criteria for selection of the case studies were:

- The use of strategies that reduce, or prevent growth of, greenhouse gas emissions
- The coverage of both Canadian and non-Canadian best practices
- Inclusion of examples from both medium and large municipalities
- Strategies that primarily focused on technological and urban design solutions, rather than economic measures
- The availability of information.

The chosen case studies (Table 4) include a wide range of strategies, essentially covering the categories established in Table 2.

TABLE 4
Capital Costs and Annual Greenhouse Gas Savings for the Case Studies

	PROJECT	LOCATION	CAPITAL COST ($ million US)	ANNUAL GHG SAVING (kt CO_2 e)
TRANSPORTATION / LAND USE				
	Light Rail Transit	Calgary	447	591(v)
	Rubber-tired streetcar	Caen	279	
	Quality Bus Corridor	Dublin	68	
	Bus Rapid Transit	Vancouver, BC	39.2	1.8
	Metrolink: Express Bus	Halifax, NS.	9.3(v)	1.125(*)
	Heavy-Duty HCNG Transit Buses-Hydrogen Highway	Port Coquitlam, BC.	2.3(v)	0.12(v)
	Low Emission Zone	London	90(v)	
	Congestion Charging	London	244(v)	120(v)
	Bike Share	Paris	132(v)	18(*)
	Bike Share	Barcelona		1.92
	Bike Campaign	Whitehorse	1.5(v)	0.0045(v)
	Real time information	Portland	6	
	High Occupancy Vehicle Lanes	Seattle	2.3 (v)	
	Parking Cash Out	California		0.24(v)
BUILDINGS				
	Demolition / Reconstruction	Toronto		31.4 (v)
	Solar Air Heating	Montreal	1.96	1.342
	Solar Hot Water Heating	Paris	0.91 (v)	0.214 (v)
	Ground Source Heat Pump	Concord, Ontario		2.862
	Building Integrated Photovoltaic	Coney Island, New York City		0.086
	Green Roof	San Francisco	2.64	
	Heat Recovery from Restaurant Exhaust	Toronto	0.015	0.0075
ENERGY				
	Solar Central Receiver Station	Seville	41	110(*)
	Solar Thermal Electricity Plant	Mojave Desert		270(*)
	Tidal Stream System	N. Ireland	5.4 (v)	2(v)
	Solar Power and Borehole Thermal Storage	Okotoks, Alberta	3.8 (v)	0.26 (v)

TABLE 4, *continued*

	PROJECT	LOCATION	CAPITAL COST ($ million US)	ANNUAL GHG SAVING (kt CO_2 e)
	Photovoltaic Plant	Olmedilla de Alarcon, Spain	460	29(*)
	Wave Power Plant	Portugal	10.6	1.8(*)
	Geothermal Power	Northern California		950(*)
	Lake Water District Air Conditioning	Toronto		79
	Small Hydro	Cordova Mines, Ontario	1.36	0.06(*)
	Urban Wind Power	Toronto	1.21	0.38
	Vertical Axis Wind	Liverpool	0.46 (v)	0.0014(*)
SOLID WASTE				
	Source-Separation & Methane Production	Sydney	75 (v)	210 (v)
	Incineration-Based CHP	Gothenburg	453 (v)	205 (v)
	Methane Capture	Toronto	24 (v)	
WATER / WASTEWATER				
	Biogas from sewage	Stockholm	15	14
	Co-Generation at Wastewater Treatment Plant	Ottawa	3.4	
	Wastewater heat recovery	Sony City, Japan		3.5 (v)
CARBON SEQUESTRATION AND OFFSETS				
	Doubling Urban Canopy	Chicago	10/year (v)	170 (v)
SUSTAINABLE COMMUNITY				
	Vauban	Freiburg		2.1
	Dockside Green	Victoria, B.C.	4.5 (v)	5.2 (v)
	Dongtan	Shanghai		750 (v) expected

(v = verified; * = GHG calculation undertaken by the project team). *Source:* Kennedy 2009

The geographical extent of the case studies is biased first towards Canada, and second towards North America and Western Europe. The locations of the case studies are shown in Figure 1. Clearly it would be useful to include more examples from other parts of the world, especially Asia[4].

Information on each case study was first assembled from websites describing the infrastructure or other relevant literature. This information was then e-mailed to owners, designers or managers of the infrastructure, who were invited to verify, update and add to the case study descriptions. Case studies for which the information has been verified are marked with a 'v' in Table 4.

FIGURE 1
Locations of Case Studies for the *Getting To Carbon Neutral* Project (as represented in a google map)

Source: adapted from the project website: www.utoronto.ca/sig.

[4] The authors would be pleased to receive further suggestions for infrastructure projects that substantially reduce GHG emissions; a form for submitting information on new case studies can be accessed on the project website: www.utoronto.ca/sig/g2cn

In some cases, information was only obtained on energy saved, or vehicle kilometers reduced, thus requiring the study team to estimate the corresponding GHG savings. For example, if the case study involved electricity supply from a renewable source, the authors established the GHG savings relative to the conventional supply, based on provincial, state or national GHG intensity as documented, for example by OPA (2007), or EIA (2006). Another illustrative example is the calculation of GHG savings related to the MetroLink express bus project in Halifax. For this, the authors multiplied the number of round trips made in the year 2008 by the average daily GHG savings per passenger, assuming that all riders used a private automobile prior to using the MetroLink. Similar assumptions are made by a number of other agencies, e.g., City of Calgary, in calculating and reporting the GHG savings of other case studies presented in this report. Case studies for which GHG savings were estimated by the authors are marked by an asterisk (*) in Table 4.

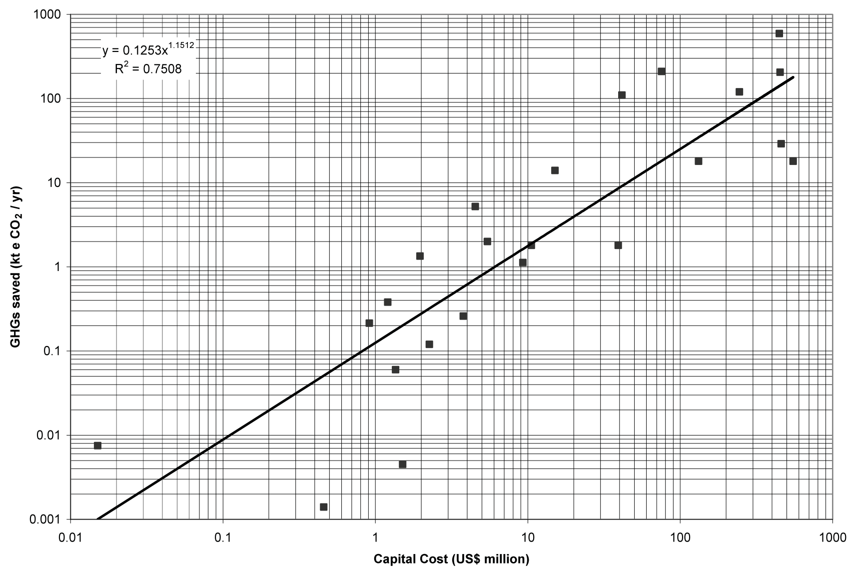
5. RESULTS

From the 68 case studies for which information was sought, data on annual GHG savings and/or capital costs was obtained for 42 cases. Of these, 34 have data on GHG savings, 30 have data on capital costs, and 22 have both sets of data (Table 4).

For the case studies where the capital costs and GHG emissions are both known there is a relatively consistent fit of increased emissions savings with higher investments (Fig. 2). The data is, however, plotted on a log-log basis, since both the costs and GHG emissions vary over orders of magnitude. The log-log plot disguises the very large deviations in the data set. For example, a bike campaign in Whitehorse costing US$1.51 million is estimated to save 45 t eCO_2 per year; while a solar air heating system in Montreal costing US$1.96 million has reported GHG savings of 1,342 t eCO_2 per year. Another comparison can be made between a subway line in Rennes, France, saving 18,000 t e CO_2 per year at a capital cost of US$550 million; and Calgary's light rail transit, powered by wind-generated electricity, which saves 591,000 t eCO_2 per year after a capital cost of US$447 million. Clearly there are significant differences in cost-effectiveness between the case studies, with respect to reducing GHG emissions.

While the line of best fit in Figure 2 is of limited use as a predictor, it helps to distinguish the infrastructure investments achieving the most cost-effective reductions in GHG emissions. Points that lie above the line, in the middle range of costs, include cases of solar hot water heating, urban wind power, tidal stream power, and generating biogas from sewage, as well as the Montreal solar air heating system.

FIGURE 2
Log-Log Plot of Annual GHG savings Versus Capital Costs for Infrastructure Case Studies in the *Getting to Carbon Neutral* (G2CN) Project



Source: Kennedy 2009.

Five case studies at the top end of Figure 2 are particularly noteworthy since they lie above the line of best fit, and exceed GHG savings of 100,000 t eCO_2 per year: These are[5]:

- Seville's Solar Central Receiver Station (Box 1)
- London's Congestion Charging Scheme (Box 2)
- Gothenburg's Combined Heat and Power (CHP) System (Box 3)
- Sydney's Source Separation and Energy Recovery Facility (Box 4)
- Calgary's Light Rail Transit System (Box 5)

[5]For detailed case study descriptions, and discussion of other benefits and implementation barriers that have been overcome, see the project website (www.utoronto.ca/sig) and Guidebook (Kennedy et al. 2009b)

BOX 1

PS10 Solar Central Receiver Station, Seville, Spain

With a peak power capacity of 11MW, Seville's Solar Central Receiver Station is the first commercial grid connected version of its type. The infrastructure consists of 624 120m2 heliostats that reflect sunlight onto a receiver at the top of a 100m tall tower, which produces steam to drive a turbine. The facility produces 24.3 GWh of electricity per year, of which only 12-15% is provided by back-up natural gas. The project cost US$55 million (IEA 2008); and it is estimated that it saves 110,000 t eCO_2 per year. There are plans to expand the system to 300MW by 2013, which would be enough to power 180,000 homes, i.e., approximately the size of Seville.

Source: Abengoa Solar 2008.

BOX 2

Congestion Charging, London, United Kingdom

Vehicles which drive within a clearly defined zone of central London between the hours of 7am and 6pm, Monday to Friday, have to pay an £8 daily Congestion Charge. Payment of the charge allows drivers to enter, drive within, and exit the Charging Zone as many times as necessary on that day. The Congestion Charge was first introduced in Central London in February 2003 with the daily charge of £5 per day to travel between 7am and 6.30pm. In July 2005 the charge rose to £8, and the zone was extended in February 2007 when the hours of operation were reduced. There is no charge for driving on the boundary roads around the zone. In addition there are a number of routes that enable vehicles to cross the zone during charging hours without paying — the Westway and a route through the centre of the zone running north to south.

If the Congestion Charge is not paid a Penalty Charge Notice (PCN) for £120 is issued to the registered keeper of the vehicle. This is reduced to £60 if paid within 14 days but if a PCN is not paid within 28 days the penalty increases to £180. Net revenue raised from Congestion Charging are spent on improving transport in London.. In 2007/08, the scheme generated a net revenue of £137m (Transport for London 2008).

London's Congestion Charging Scheme is estimated to have reduced emissions by 120,000 t eCO_2 per year; it cost about US$324 million to implement, including traffic management measures, communications / public information, systems set-up and management

Source: Evans 2008.

BOX 3

CHP from Solid Waste, Gothenburg, Sweden

Gothenburg's Combined Heat and Power (CHP) system, fuelled by waste incineration, reduces municipal solid waste disposal needs and displaces fossil fuel generated heat and electricity. Approximately 1,200,000 MWh of electricity were produced from incineration of waste in 2006. Annual benefits from the sale of electricity are US$33.6 million. Other benefits may include avoided landfill disposal costs and carbon credits. The system cost US$600 million; and saves about 205,000 t eCO_2 per year through separation and combustion of degradable organic carbon.

Source: Climate Leadership Group 2008a.

BOX 4

Source Separation and Energy Recovery, Sydney, Australia

Sydney's Source Separation and Energy Recovery Facility achieves a 70% diversion of municipal solid waste from landfill. An anaerobic digestion process produces methane, which is combusted to produce electricity to power the separation facility. Compost from the organic stream is sold for US$20-US$30 per tonne. The estimated GHG savings are 210,000 t eCO_2 per year, as landfill gas emissions are avoided through separation / combustion of degradable organic carbon. The facility was constructed with a capital cost of US$100 million.

Source: Climate Leadership Group 2008b.

BOX 5

Calgary C-Train, Alberta, Canada — Ride the Wind!

The C-Train is Calgary's light rail transit system. The system uses 39,477 MWh of electricity annually (2007 data), which the city purchases from ENMAX Energy Corporation, the city's electrical distribution provider (Inglis 2009). The program, branded as Ride the Wind, powers the C-Train using wind energy supplied by twelve 600 kilowatt turbines. These are installed in southern Alberta on the tops of hills facing the Rockies, in order to take advantage of the strong westerly winds coming from the mountain passes. The C-Train is now 100% emissions free. It is the first public Light Rail Transit system in North America to power its train fleet with wind-generated electricity (Ride the Wind 2008).

Following capital investment of US$447 million (in the transit system and wind turbines), Calgary's C-train saves around 590,000 t eCO_2 per year (Inglis 2009). Each day (Monday to Friday), riders board the C-Train 290,000 times. If each commuter had traveled alone in his or her car instead of on the C-Train, the daily mileage would have amounted to 2.32 million kilometres. These car commuters would have used 238,300 litres of fuel, and produced some 590,656 tonnes of carbon dioxide, as well as other pollutants such as nitrous oxide, carbon monoxide, and particulate matter.

Source: Ride the Wind 2008; Inglis 2009.

In addition to the above five cases, the data set includes four other projects with annual GHG savings over 100,000 t eCO_2, but for which the capital costs are not available to the study team. These are: a solar thermal electricity plant in the Mojave desert (270,000 t eCO_2 per year); a series of over twenty geothermal power plants in Northern California (950,000 t eCO_2 per year); Chicago's plan to double its tree canopy (170,000 t eCO_2 per year); and the planned Dongtan sustainable community development near Shanghai (750,000 t eCO_2 per year). However, it must be mentioned that doubts have been raised on whether the Dongtan development will proceed (The Economist Mar 19, 2009).

The case studies mentioned above, with savings over 100,000 t eCO_2 per year, cover a variety of sectors: transportation, solid waste, energy and urban forestry. This is encouraging, as it shows that a diverse range of effective strategies can be adopted to reduce emissions. For some of these nine case studies, it is clear that the strategy adopted exploits local conditions, such as high solar radiation, or suitable conditions for geothermal energy. In other cases, the strategy was a response to local stresses, e.g., traffic congestion in London, heat waves in Chicago; but for some cases it was just a matter of being more creative and efficient with solid waste.

6. COMPARISON WITH OTHER DATA SETS

The results from the G2CN case studies discussed in this paper can be compared to those from two other data sets:

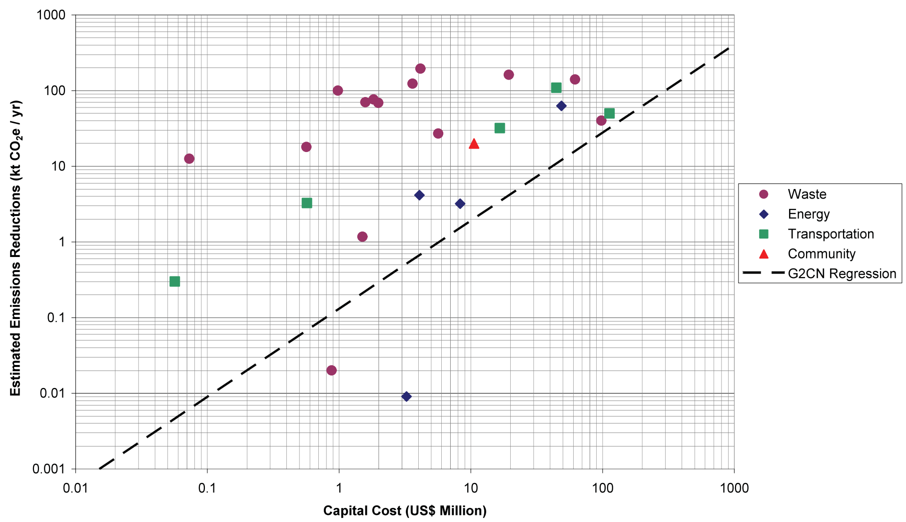
i) The Federation of Canadian Municipalities (FCM) records the expected savings in GHG emissions from some projects supported by the Green Municipal Funds. These funds, which were endowed by the Canadian Government, provide grants and below-market loans to directly support municipal initiatives in Canada.

ii) The United Nations Framework Convention on Climate Change (UNFCCC) has a database of projects funded under the Clean Development Mechanism (CDM). The CDM arrangement, developed under the Kyoto Protocol, allows industrialized countries to invest in emissions reduction projects in developing countries, as alternatives to more expensive strategies in their own countries.

The majority of projects in the FCM database, for which both GHG savings and capital costs are reported, are in the solid waste sector (twelve). In addition, data is available for four transportation projects, four energy supply projects, and one community development project – an eco-industrial park in Hinton, Alberta (Canada).

Generally speaking, the nine data for the non-waste sectors are distributed in a relatively similar manner to our case study data (again on a log-log plot). The line of best fit of G2CN data, from Figure 2, is shown with the FCM data in Figure 3 for comparison. The cost-effectiveness of the nine non-waste sector projects (2,040 t e CO_2 / yr / US\$million) is on average better than for the G2CN case studies (550 t e CO_2 / yr / US\$million); eight of the nine points lie above the regression line of G2CN data. Furthermore, it is quite apparent that the solid waste projects in the FCM dataset substantially out-perform the data from G2CN case studies. The average cost-effectiveness of the FCM solid waste projects is 37,400 t e CO_2 / yr / US\$million.

FIGURE 3
Log-Log Plot of Annual GHG Savings Versus Capital Costs for Infrastructure Projects Funded Under the Federation of Canadian Municipalities "Green Municipal Fund"

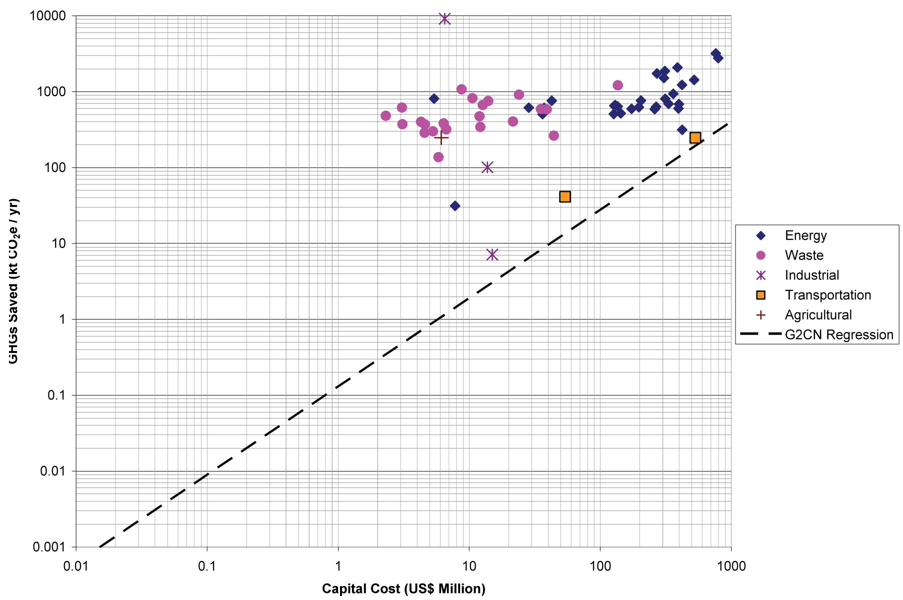


The dotted line is from the regression of G2CN data shown in Figure 2. *Source:* FCM 2009; Kennedy 2009.

The United Nations database of CDM projects was accessed on-line between January and April, 2009. At this time, there were over 1,500 registered CDM projects, with several thousand more under review. Capital cost data are taken from project design documents, assuming that capital cost was equal to incremental cost for the project (thus operations and maintenance costs are ignored), and that the baseline scenario is to do nothing. Conversions of costs are made to US dollars as of the project registration date[6]. Where capital costs could not be located in the project design document, the project was not included as a data point. There are many solid waste and energy projects in the database. Figure 4 plots waste and energy projects at the high end of expected GHG reductions, i.e. all energy projects over 500,000 t e CO_2 / yr, and all waste projects over 250,000 t e CO_2 / yr are shown, as well as a few other smaller scale projects that were of interest to the study team, and some agricultural and industrial projects. There are also a small number of transportation and afforestation / reforestation projects in the CDM database; these are plotted in Figure 4 as well.

[6] using the currency conversion website Oanda.com at the inter-bank rate

Figure 4
Log-log Plot of Annual GHG Savings Versus Capital Costs for a Subset of United Nations Clean Development Mechanism Infrastructure Projects



The dotted line is from the regression of G2CN data shown in Figure 2. *Source:* UNFCC 2009; Kennedy 2009.

In comparison to the G2CN data, the CDM projects are much more cost-effective, as should be expected for developing countries. All of the CDM projects lie above the regression line for the G2CN data. The spread amongst the CDM projects is quite remarkable. For example, the Alto-Tietê landfill gas capture project in Brazil has certified reductions of 481,000 t eCO_2/yr for a capital cost of US$2.31 million, while a bus rapid transit project in Bogota, Colombia saves 247,000 t eCO_2/yr, at a capital cost of US$532 million. As with the FCM data, the solid waste projects are the *low hanging fruit* in terms of cost-effectiveness. This is apparent when comparing the energy and waste projects in Figure 4 (again recognizing that these are partial data). The average cost-effectiveness of the CDM waste projects is 64,800 t eCO_2/yr / US$million, compared to 10,300 t eCO_2/yr / US$million for energy projects.

7. LIMITATIONS

Several caveats apply to the interpretation of the results above and the comparisons with other datasets. First, the estimation of GHG emissions for projects in the dataset used for the study has not necessarily been undertaken with a consistent methodology. Other than the few cases where the authors calculated the GHG savings, the quality of the dataset depends on the calculations undertaken individually for each project by the concerned project team.

Furthermore, the study team has undertaken a broad scan of infrastructure strategies for reducing GHG emissions. Generally, only one or two cases of a particular type of strategy are included in the dataset, and these may not necessarily be representative of the average performance of such a strategy. Where there is multiple data for a particular strategy, such as landfill gas to energy in the CDM and FCM datasets, then a high degree of variation in cost-effectiveness is apparent.

Part of the variation in costs and GHG savings between projects can be attributed to differences in local conditions. Costs of projects vary due to factors such as costs of labour, access to resources, access to technology, economies of scale, etc. GHG emissions saved when generating electricity from renewable sources depend on the GHG intensity of the local power grid. So even if costs are the same, the cost-effectiveness is higher in regions that currently have greater dependence on coal for power generation. GHG reduction strategies that are cost effective in one region may not be so in another.

Several of the projects considered in the dataset are cutting edge applications of new or developing technologies. As such the costs of these projects, which may be considered trials or experiments, can be expected to come down as the technology develops.

Another important caveat is that few, if any, of the infrastructure projects considered in the dataset were designed solely for the purpose of reducing GHG emissions. Reducing emissions is only one goal. Transportation systems are designed to move people and goods; energy infrastructure is designed to provide heating, lighting and electrical service, etc. By virtue of differences in their functionality, various types of infrastructure can be expected to differ in terms of cost effectiveness for reducing GHGs; this is less apparent with the G2CN data, but clearly the case with the FCM and CDM datasets.

Finally, while cost-effectiveness has some merits as an economic measure, it is of limited use from an investment perspective. The private sector, in particular, must expect to achieve satisfactory rates of return if it is to invest in infrastructure that reduces GHG emissions. OECD/IEA (2008) have identified a number of energy efficiency initiatives in a few cities, such as building retrofits, LED (Light Emitting Diode) traffic signals, and pool heat recovery, for which rates of return of over 100% are achieved.. Kikuchi et al. (2009) have also shown that investments in alternative energy technologies in Ontario can offer investors reasonable rates of return at relatively low risk, depending on the sector. The investments considered in both of the above studies are, however, relatively small scale. Further studies of returns on investment are perhaps warranted with respect to infrastructure projects that substantially reduce GHG emissions.

8. CONCLUSIONS

The case studies presented in this paper cover a variety of infrastructure strategies with savings in GHG emissions ranging from 45 t eCO_2 to over 500,000 t eCO_2. The size of the GHG reductions generally increases with the magnitude of capital investment, as expected, but there is significant variation. Measures of cost-effectiveness vary between 3 and 2,780 t eCO_2/ yr / US$million for the database.

The average cost-effectiveness of the G2CN database is 550 t eCO_2/yr / US$million. This could be used as a benchmark to compare GHG savings for urban infrastructure investments in developed nations. However, much higher levels of cost-effectiveness have been achieved with solid waste projects in Canada (FCM); and with developing world CDM projects. Thus a higher benchmark should perhaps be set for infrastructure projects in developed world cities, depending upon the type of infrastructure available.

This paper has highlighted five case studies in particular, which are above the average cost-effectiveness achieved in the G2CN dataset, and have GHG savings over 100,000 t eCO_2. These are: a solar central receiver station in Seville; the congestion charging scheme in London; CHP in Gothenburg; source separation and energy recovery in Sydney; and light rail transit in Calgary. A further four projects in the database have GHG savings over 100,000 t eCO_2, but the capital costs of these initiatives are not available to the authors.

While the GHG savings from the nine cases are substantial, these should be assessed with reference to the GHG inventories of cities. A GHG saving of 100,000 t eCO_2 per year is still two orders of magnitude below the typical emissions for a city of 1 million people, and three orders of magnitude below that for a mega-region, as discussed in the introduction (Table 1). Cities arguably need to start planning projects with reductions of the order 1 million plus t eCO_2 per year.

Acknowledgements

Financial support for this work was provided by Toronto and Region Conservation Authority.

References

Abengoa Solar. 2008. "PS10: The First Commercial Tower of the World." http://www.abengoasolar.com/sites/solar/en/our_projects/solucar/ps10/index.html. [Accessed November, 2008].

Climate Leadership Group. 2008a. "Best Practices." Gothenburg, Sweden: C40 Cities. http://www.c40cities.org/bestpractices. [Accessed November 7, 2008].

Climate Leadership Group. 2008b. "Best Practices." Sydney, Australia: C40 Cities. http://www.c40cities.org/bestpractices. [Accessed November 7, 2008].

Codoban N., and C. A. Kennedy. 2008. "The Metabolism of Neighborhoods." ASCE J. of Urban Planning and Development 134 (1): 21–31.

Dong B., C. A. Kennedy, and K. Pressnail. 2005. "Comparing Life Cycle Implications of Building Retrofit and Replacement Options." Canadian Journal for Civil Engineering 32 (6): 1051–63.

Engel Yan J., C. A. Kennedy, S. Saiz, and K. Pressnail. 2005. "Towards Sustainable Neighbourhoods: The Need to Consider Infrastructure Interactions." *Canadian Journal for Civil Engineering* 32 (1): 45–57.

Evans, R. 2008. "Central London Congestion Charging Scheme: Ex-Post Evaluation of the Quantified Impacts of the Original Scheme." Transport for London. http://www.tfl.gov.uk/assets/downloads/Ex-post-evaluation-of-quantified-impacts-of-original-scheme-07-June.pdf. [Accessed November 8, 2008].

FCM. 2009. Federation of Canadian Municipalities. http://gmf.fcm.ca/Search/Search/Search.aspx?lang=e (Green Municipal Fund Approved Projects Database; accessed April 2009).

IEA SolarPaces. 2008. Spain PS10, http://www.solarpaces.org/Tasks/Task1/PS10.HTM, [Accessed October, 2008].

Inglis, P. 2009. Personal correspondence with The City of Calgary.

Kennedy, C. A. 2002. "A Comparison of the Sustainability of Public and Private Transportation Systems: Study of the Greater Toronto Area." *Transportation* 29: 459–93.

______. 2007. "Applying Industrial Ecology to Design a Sustainable Built Environment: The Toronto Port Lands Challenge." Paper presented at the Engineering Sustainability Conference, Pittsburgh, USA, April 15-18.

Kennedy, C. A., and E. Mohareb. 2009. To be published in 2010. "Greenhouse Gas Emissions from Cities." Chapter 7 in *Cities in Evolution: Urbanization, Environmental Change and Sustainability*, ed. Xuemei Bai, Thomas Graedel and Akio Morishima. Cambridge University Press.

Kennedy, C. A., E. Miller, A. Shalaby, H. MacLean, and J. Coleman. 2005. "The Four Pillars of Sustainable Urban Transportation." *Transport Reviews* 25 (4): 393–414.

Kennedy, C. A., J. Cuddihy, Yan J. Engel. 2007. "The Changing Metabolism of Cities." *Industrial Ecology* 11 (2): 43–59.

Kennedy, C., J. Steinberger, B. Gasson, T. Hillman, M. Havránek, Y. Hansen, D. Pataki, A. Phdungsilp, A. Ramaswami, G. Villalba Mendez. 2009. "Greenhouse Gas Emissions from Global Cities." *Environmental Science and Technology* 43: 7297–302.

Kennedy, C. A., ed. 2009. *Getting to Carbon Neutral: A Guide for Canadian Municipalities*. Prepared for the Toronto and Region Conservation Authority. http://www.utoronto.ca/sig.

Kikuchi, E, D. Bristow, and C. A. Kennedy. 2009. "Evaluation of Region-specific Residential Energy Systems for GHG reductions: Case Studies in Canadian Cities." *Energy Policy* 37 (4): 1257–66.

OECD/IEA. 2008. "Promoting Energy Efficiency, Best Practice in Cities: A Pilot Study." Working Paper, IEA, Paris.

OPA (Ontario Power Authority). 2007. "Integrated Power Systems Plan." http://www.powerauthority.on.ca/Page.asp?PageID=1224&SiteNodeID=320. [Accessed April 2008].

Racoviceanu, A, B.W. Karney, C. A. Kennedy and A. F. Colombo. 2007. "Life Cycle Energy Use and Greenhouse Gas Emissions Inventory for Water Treatment Systems." *ASCE J. of Infrastructure Systems* 13 (4): 261–70.

Ride the Wind! 2008. The C-Train, Re-Energy. http://www.re-energy.ca/ridethewind/backgrounder.shtml. [Accessed November 7, 2008].

Sahely, H. R., and C. A. Kennedy. 2007. "Integrated Systems Flow Model for Quantifying Environmental and Economic Sustainability Indicators: Case Study of the City of Toronto Urban Water System." *ASCE Journal of Water Resources Planning and Management* 133 (6): 550-–9.

Sahely, H. R., S. Dudding and C. A. Kennedy. 2003. "Estimating the Urban Metabolism of Canadian Cities: GTA Case Study." *Canadian Journal for Civil Engineering* 30: 468–83.

Saiz, S, C. A. Kennedy, B. Bass, and K. Pressnail. 2006. "Comparative Life Cycle Assessment of Standard and Green Roofs." *Environmental Science and Technology* 40 (13): 4312–16.

Transport for London. 2008. *Congestion Charging, Transport for London*. http://www.tfl.gov.uk/roadusers/congestioncharging/. [Accessed November 8, 2008].

TRCA (Toronto and Region Conservation Authority) Living City Project. 2008. www.trca.on.ca/Website/TRCA/website.nsf/WebPage/thelivingcity/. [Accessed Sept 2008].

UNFCCC (United Nations Framework Convention on Climate Change) Clean Development Mechanism Database. http://cdm.unfccc.int/Projects/projsearch.html. [Accessed April 2009].

US EIA (Energy Information Administration). 2006. State Electricity Profiles. http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html. [Accessed Feb. 2009].

Zachariah, L, C. A. Kennedy, and K. Pressnail. 2002. "What Makes a Building Green?" *International Journal of Environmental Technology and Management* 2 (1-3): 38–53.

Abbreviations

CDM	Clean Development Mechanism
CHP	Combined Heat and Power
FCM	Federation of Canadian Municipalities
GHG	Greenhouse Gas
G2CN	Getting to Carbon Neutral
t e CO_2	Tones of Carbon Dioxide equivalents
PCP	Partners for Climate Protection
ICLEI	International Council for Local Environmental Initiatives
LED	Light Emitting Diode

CHAPTER 8

Towards CO_2 Neutral City Planning —the Rotterdam Energy Approach and Planning (REAP)

Andy van den Dobbelsteen,* Nico Tillie, Marc Joubert, Wim de Jager, Duzan Doepel

Summary

By the year 2025 the city of Rotterdam, with the largest port in Europe, aims to reduce its CO_2 emissions by half, an ambitious plan that will require a revolutionary approach to urban areas. One proactive response to this challenge is an exploratory study of the Hart van Zuid district. An interdisciplinary team has investigated how to tackle CO2 issues in a structured way. This has resulted in the Rotterdam Energy Approach and Planning (REAP) methodology. REAP supports initial demand for energy, propagates the use of waste flows and advocates use of renewable energy sources to satisfy the remaining demand. REAP can be applied at all levels: individual buildings, clusters of buildings and even whole neighborhoods. Applying REAP to the Hart van Zuid district has shown that this area can become carbon neutral. Most importantly, REAP can be applied regardless of location.

Key Words: REAP, Rotterdam Energy Approach and Panning, carbon neutral city planning, closed cycles, sustainability, sustainable urban planning, sustainable architecture, urban development.

*Corresponding author: A.A.J.F.vandenDobbelsteen@tudelft.nl

1 INTRODUCTION

1.1 Prospects for the Future

Ten years ago few people thought that the climate was changing and even fewer realized that mankind was influencing the change. Since then opinions have altered and now the world is generally convinced of the seriousness of the situation: the climate is changing at an unprecedented rate, mankind is one of the major causes as acknowledged by the IPCC [1] and fossil fuels are rapidly depleting. Because of this, attention is concentrated on energy consumption and the consequences of this. However, there are other forms of damage to both the environment and public health that must not be ignored. It is possible to arm ourselves against, or if required to flee, the consequences of climate change. However the biggest social problem is not climate change but the depletion of energy reserves; a socio-economic problem rather than a technical one. This will have far reaching consequences for what can and cannot be achieved. Industrialized nations are highly dependent on the easy supply of fossil energy. Just before the start of the current world-wide economic crisis the price of oil reached a previously inconceivably high level (nearly 145 USD a barrel) and, at the time, experts expected the price to double. A price of more than 100 USD a barrel has serious consequences, which could be seen in the reduction in sales of petrol guzzling SUVs in America. Energy affects everyone, but especially the poor and the people living the farthest away from amenities. Already by 2010 the price of oil had again reached a level of $110 a barrel. It would be wise to use the present crisis as the impetus to develop a different energy system.

1.2 Energy

The energy crisis does not mean that individual countries have to cut themselves off from the outside world and only use energy that can be generated within its own borders — even if that were possible — but it is wise to make better use of within-country energy potential. The continental area of the Netherlands is sufficient to generate enough solar energy to supply the economy of the whole world [2]. Technically it is possible to realize a completely sustainable energy system but, for the time being, costs are prohibitive. A current requirement is an assessment of resources and intelligent methods for using them appropriately. In built-up areas it is important to target the following measures:

1. Applying renewable energy sources. Within the foreseeable future there will simply be no other sources.

2. Making use of the available energy potential. This is an interpretation of the first measure at local level: renewable energy could be imported but it is far better to make use of local opportunities.
3. Making better use of waste streams. All buildings and urban areas generate waste flows that could be harnessed but rarely are. Making use of these waste flows would reduce the primary demand and so aid the introduction of sustainable energy sources.
4. Intelligent and bioclimatic design of buildings. This refers to making intelligent use of local conditions — climate, soil and environment — in the design of buildings and districts. Buildings and neighborhoods are no longer seen as objects out of context.
5. Energy savings in existing buildings: this will continue to be necessary as in 2025 (the period by which the city of Rotterdam must have halved its CO_2 emissions) around 90% of the built-up region will be made up of the buildings that are here today and which are frequently far from energy efficient.

1.3 The Three Stepped Strategy for Energy

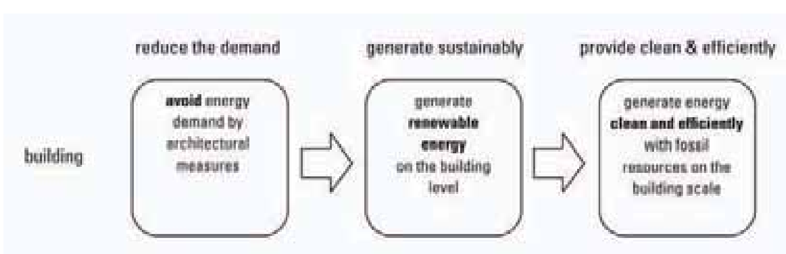
Since the end of the 1980s sustainable approaches to urban areas have followed the three step strategy (see Figure 1):

Step 01 Reduce demand

Step 02 Use renewable energy

Step 03 Supply the remaining demand cleanly and efficiently

Figure 1
The Trias Energetica, the Three Stepped Strategy for Energy [3]



This strategy towards energy use is known as the Trias Energetica [3]. It forms the guideline for a logical, environmentally conscious approach but in the twenty years that it has been in use, it has not led to the required sustainability. In particular, the degree of penetration of renewable energy sources, Step 2, has been minimal. Sustainable building in the Netherlands mainly concentrates on Step 3 which, in practice, is often mixed up with Step 1. The Netherlands, which has been using the Trias Energetica since the early 1990s, has a very limited use of solar, wind and other renewable energy technology in comparison with other European countries. This is probably related to the Trias Energetica. If Step 2 abruptly follows a sub-optimal reduction in energy demand in Step 1, a great demand for energy still needs to be met by renewable in Step 2, which so far has been economically unfeasible. In practice this leads in quick succession to Step 3 – the use of traditional, albeit more efficient, technology. Hence, in our opinion an important intermediate step, which would make the use of renewables better feasible, has not been explicitly mentioned.

1.4 The New Stepped Strategy

The New Stepped Strategy adds an important intermediate step in between the reduction in demand and the development of sustainable sources, and incorporates a waste products strategy [4] (partially inspired by the Cradle-to-Cradle philosophy [5]):

Step 01 Reduce demand (using intelligent and bioclimatic design)

Step 02 Reuse waste energy streams

Step 03 Use renewable energy sources and ensure that waste is reused as food

Step 04 ~~Supply the remaining demand cleanly and efficiently~~

FIGURE 2
The New Stepped Strategy, Inserting a Step and Omitting the Last Step of the Trias Energetica [4]

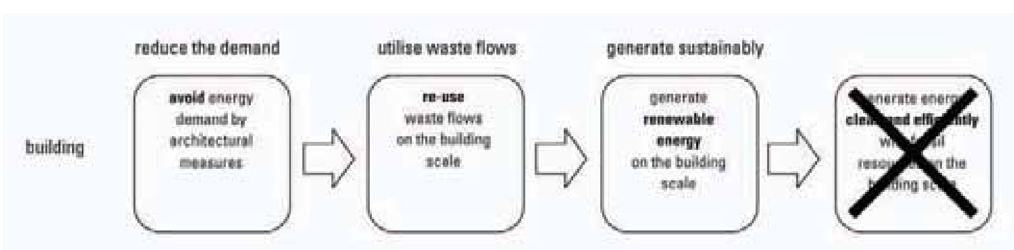
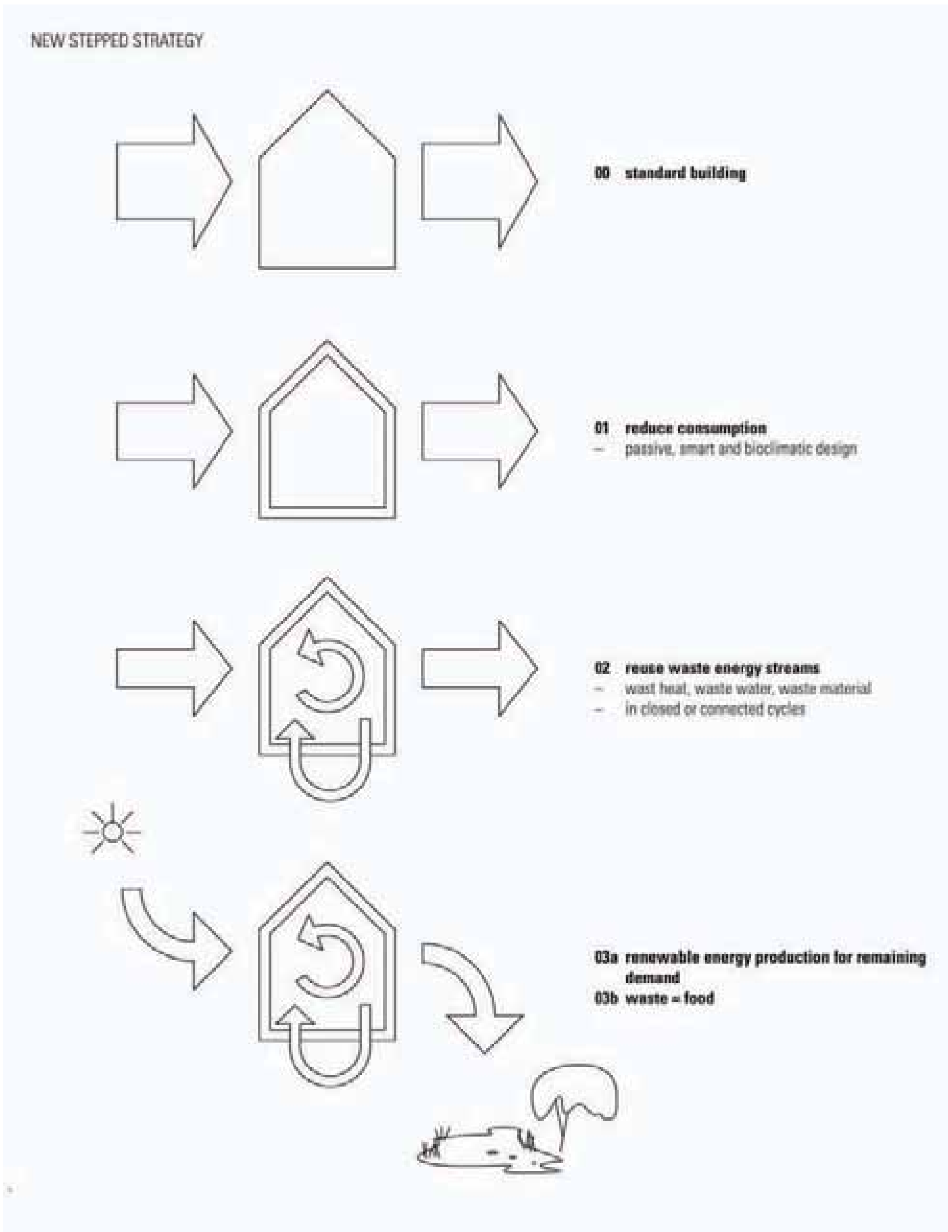


FIGURE 3
The New Stepped Strategy at the Building Level [4, 8]



As can be seen, the New Stepped Strategy has a new second step that makes optimal use of waste flows — waste heat, waste water and waste material — not only for each individual building but also on a city-wide scale. Waste flows from one chain may be used in a different chain. For example, waste water can be purified and the silt fermented to form bio-gas which can be reused in the energy chain. The addition in step 3 (really 3b) concerns waste that cannot be processed in a technical waste processing cycle and so must be returned to nature. This can only be done if the waste is safe (non-toxic) and if it can form nutrients for micro-organisms.

Step 4 will continue to be necessary for the coming years, but eventually this will no longer be possible or desired when all energy in the built environment can be produced by renewables. The development of new areas or the redevelopment of existing areas should already take this into account because the fourth step will remain a painful necessity in many other regions.

1.5 Old Energy System Versus Sustainable Energy System

Considering the organization of the energy system, by 2010 only 96% was generated from fossil or nuclear sources but at the same time a lot of heat is lost (in the air, water or ground) and many potentially useful by-products are wasted. A source such as natural gas is delivered to all public and private amenities. Taking the quality of energy into account (exergy) this is a significant potential loss of energy. A gas flame of 1,200 – 1,500°C is much more appropriate for high-grade industrial processes (that actually require such high temperatures) than for heating a home to 20°C. If homes are intelligently designed then a temperature of 25 to 40°C is more than sufficient for the heating; this temperature is released as waste heat by many kinds of processes (e.g. greenhouses or cooling systems in offices). Other amenities require higher temperatures, but these could be achieved using waste heat from other higher-grade processes. A more sustainable system based on the usage of this waste would require significantly less primary energy and this primary energy would only be used by the most high-grade functions (a low-exergetic system) [6]. Although not an efficient system, it can be very effective: sustainability could be theoretically increased six-fold, while the current plans for improvement may only increase efficiency by as little as 10%.

2 THE REAP METHODOLOGY

2.1 From Building to Neighborhood

If the New Stepped Strategy is applied to an individual building it will undoubtedly generate a more sustainable building, but within the whole urban context this would be a waste – or a missed opportunity. No use is made of the direct surroundings. The energy demand per building can, and must, be reduced. After this it is useful to determine whether waste flows from the building can be usefully employed. This is already being done, for example, by recycling heat from ventilated air and waste shower water. However, it is much more difficult to purify wastewater from each building to reclaim bio-gas. In short: after step 2 a significant demand for energy remains which, according to step 3, must be solved using renewable energy sources. As has already been mentioned, this is technically possible but requires huge investment. A better idea is to consider a cluster of buildings and to determine whether energy can be exchanged, stored or cascaded (see schematic diagram). In other words, if at individual building level all the waste heat has been recycled, the remaining demand for heat or cooling can probably be solved by buildings with a different pattern of energy requirements, buildings with an excess of the required energy or which produce waste heat (or cold).

1. An example of exchange: due to internal heat production, modern offices start cooling as soon as outdoor temperatures exceed 12°C. At these temperatures homes still require heating. This provides opportunities for heat exchange during spring and autumn. Another example is the combination of supermarkets (always cooling) with homes (frequent heating).

2. An example of energy storage at cluster level: heat and cold are only available in excess when there is little demand for them. For an optimal energy balance, energy should be stored during seasons when the exchange, as mentioned in example 1, is not required.

3. An example of cascading: a greenhouse captures much passive solar energy which usually disappears as waste heat into the air. A heat exchanger could enable this waste stream (usually about 30°C) to be used to heat homes, provided these homes are well insulated and make use of a low-temperature heating system. If all waste flows at cluster level are being used optimally it then becomes possible to see if primary energy can be generated sustainably. Although solar panels, solar collectors, or a heat pump with a ground collector system can be installed in each individual building, it is much more economical to set these up at cluster level.

2.2 From Neighborhood to District

If a project can be tackled at an even higher level, such as district level, potential discrepancies in the energy balance at neighborhood level (for example excess demand for waste heat or cold) may be solved. At district level it is reasonable to assume that other functions are available with a totally different demand, and therefore, supply pattern. And just as at cluster level, it is also possible to exchange, to store and to cascade energy (see the schematic diagram of Figure 4). Certainly at the larger amenities, such as shopping centers, swimming pools and concert halls, the energy pattern is so specific that by combining a number of these different amenities it is likely that an energy balance can be achieved. Hart van Zuid provides good opportunities for this.

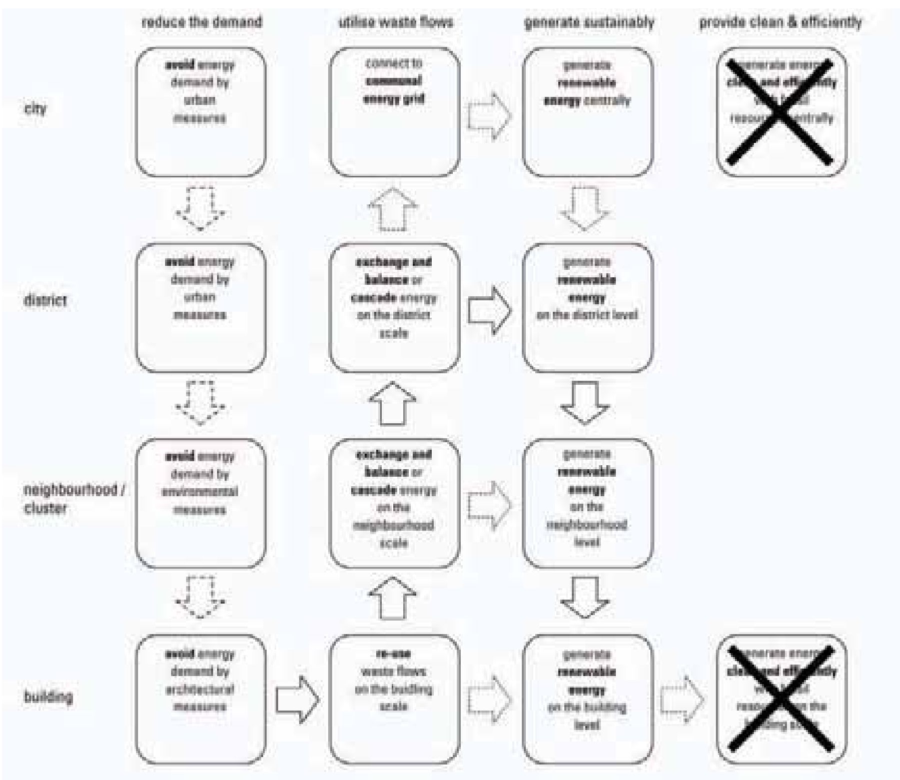
In addition to exchange, storage and cascading, another option is possible at neighborhood level: energetic implants. This is an intriguing term for adding a function to complete missing links in the energy supply chain. Once the existing amenities in the area have been optimally tuned to each other (here, as an example, only the heat balance is considered) a residual demand for heat or cold (but not both) will still exist. In this case it is only necessary to look for an amenity that requires extra heat (for example, a swimming pool) or cold (for example, an ice rink) on a yearly basis. The provision of renewable energy can then be tackled at district level. As has already been said, some sustainable measures can be implemented at building or neighborhood level, but other more capital intensive projects are more appropriate at district level. An example of this is the bio-gas fermentation installations that recycle bio-gas from wastewater and use power-heat coupling (CHP) to generate heat and electricity. Geothermal energy is also only feasible on a grand scale.

2.3 From District to Entire City and Beyond

The next step to a higher level would be the city or region, the scale in which our current amenities are generally centrally regulated. In the city of Rotterdam the city heating network is fed with waste heat from the electricity generators. City heating provides heat at temperatures between 90 and 130°C. This is perfect for old buildings which are poorly insulated and with central heating systems based on 90 to 70°C. However, in new housing projects the buildings are much better insulated and would be better served with a heating system based on lower temperatures, such as floor and wall heating using temperatures lower than 50°C. Most modern homes would even be fine with temperatures lower than 30°C. City heating is unnecessary for these buildings. Once a connection to the city heating is necessary or desired, the whole exercise of exchange, storage and cascading at neighborhood and district level is no longer necessary (see Figure 5). In that case the city heating takes care of the heating and potentially also the cooling (via absorption cooling).

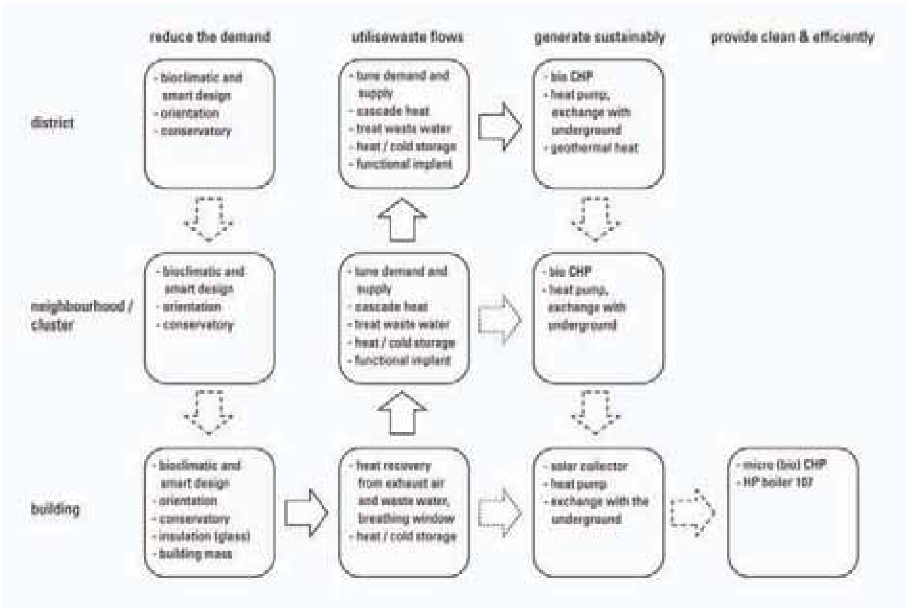
The problem with this is that the local waste heat can no longer be made useful and disappears into the environment — the urban or natural surroundings. Given the climate change expected worldwide and in cities [1, 7] — in which cities will become warmer, both directly and indirectly — this situation is not desirable. For this reason the REAP methodology aims first at solving the problems of energy demand and supply on a small scale, after which 'help' can be called in from higher levels. In addition, the city heating can fulfill a useful role as a backup system, or as a loading and unloading system for heat imbalances in a district or neighborhood. REAP can help make an existing neighborhood sustainable, without requiring drastic urban planning measures. The following chapters will not only show that this can lead to carbon neutral neighborhoods but also how this can be done [8].

FIGURE 4
The REAP Methodology



Normally the process would start with the two steps at the lower left corner, with energy renovation of existing buildings (firstly reducing the demand, secondly adding heat-recovery systems). Instead of immediately proceeding to supplying the remaining demand through renewables, it is more effective to study whether exchanging energy with the built environment is an option, either the neighborhood or district, before solving the final demand by renewables at all scales. [8]

FIGURE 5
The REAP-methodology exemplified for heat and cold [8]



3 THE CASE OF HART VAN ZUID

How can REAP be applied to an existing, complex urban area — in this case, the Hart van Zuid district? Which decisions within the methodology must be made if the desired reductions in CO_2 emissions are to be achieved — decisions at economic, political, public, urban development and architectural level? And what are the consequences for the buildings in a city and the open spaces in between? In addition, the examples explicitly look for combinations of measures for CO_2 reduction, together with sustainable development.

How can this cluster, with its mix of 1960s urban development and 1980s architecture, once again become attractive in and for the city? It is currently mainly a shopping centre, attracting people from the south of the city, with an unusual mix of infrastructure (e.g. the second busiest bus station in the Netherlands) and a theatre, but with no activities after opening times and no links to the surrounding areas. At the same time, the buildings devour energy; heating in the winter and cooling in the summer. How can this urban development problem, coupled with Rotterdam's CO_2 targets, be transformed into a future-oriented, attractive development?

Step 00 Make an inventory of the current energy demand.

Step 01 Reduce the demand > New functions will be added: 20,000 m2 shops, 6,000 m2 supermarket. Theatre Zuidplein and the infrastructure intersection will be renewed. Better insulation of the existing shopping centre will in itself already significantly improve the situation.

Step 02 Reuse of waste flows > The addition of housing will create a better heat-cold balance. The use of the waste heat generated by the supermarket and the typical morning and evening energy demand in homes means that the match is perfect: 1m2 supermarket can heat 7m2 of housing! If 665 apartments are added, the heat-cold ratio becomes 1:1.08 assuming that use is made of heat and cold storage (Figures 6 and 7).

Step 03 Renewable energy generation > The remaining demand for heat can be solved by the addition of greenhouses on the first floor. These could be public areas (or greenhouses for growing tomatoes) or by the addition of PVT-panels. PV panels could also be installed on the roof to supply electricity for the whole shopping centre. The remaining energy required could be sustainably generated at a higher scale level. (Figure 8)

FIGURE 6
Summer Situation: Energy Demand of the Total Program, Heat (H), -865 GJ, Cold (C) -5475 GJ, Electricity -7034 GJ [8]

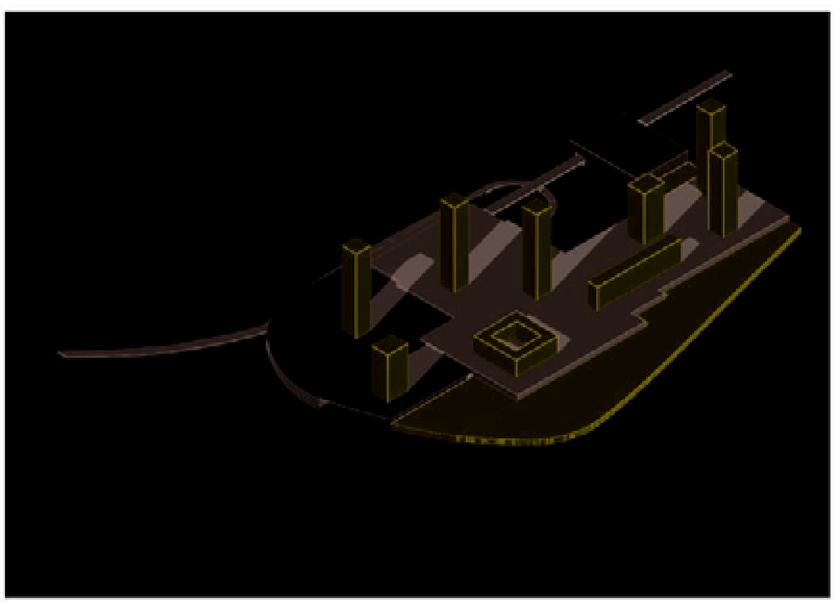


FIGURE 7
Winter Situation: Energy Demand of the Total Program, Heat (H), -7788 GJ, Cold (C) -1755 GJ, Electricity -7595 GJ [8]

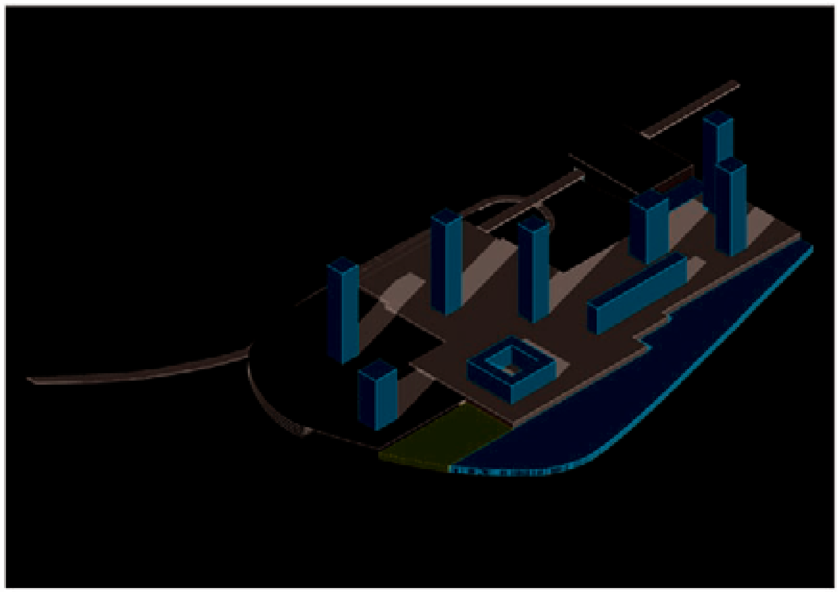
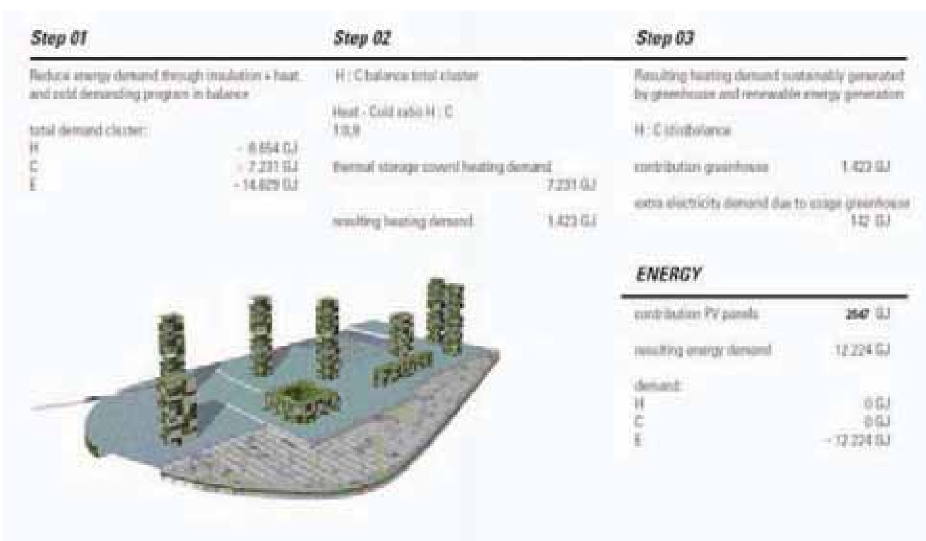


FIGURE 8
Energy Balance and Remaining Energy Demand to be Solved at a Higher Scale [8]



3.1 Motorstraat Area in the Hart van Zuid District

In this area with a school and some smaller businesses, the aim is to build two new colleges on the redeveloped Motorstraat ('Motor Street'). This provides an opportunity for developing a balanced, multi-functional cluster. But which functions can be sustainably combined, taking energy, social and economic issues into account?

A combination with housing improves social integration in the area by ensuring that the area is used throughout the day. Adding offices strengthens this mix. To achieve an energy balance in this cluster the intended 50m Hart van Zuid swimming pool can be combined with a new ice rink. The waste heat from the ice rink in combination with the swimming pool's permanent demand for heat provide an opportunity for using thermal storage to create energy balance. The remaining demand for heat can be satisfied using a combination of solar collectors and greenhouses.

Step 00 Make an inventory of the current energy demand > This is to be a newly-built area so right from the start the perfect function mix can be set up. New functions are added to the cluster based around two new intermediate vocational colleges.

Step 01 Reduce energy demand > The most up-to-date techniques in energy saving will be used (Figure 9).

Step 02 Reuse waste flows > Balancing the heat-cold relationship by the addition of functions: 50 m swimming pool (permanent need for heat), ice rink (permanent need for cooling) as well as homes and offices (Figures 10 and 11).

Step 03 Renewable energy generation > The resulting demand for heat can be completely satisfied by the addition of solar collectors on the roofs and the incorporation of a greenhouse in between the various functions. This greenhouse will also provide an additional (productive) space. Any remaining energy requirements will be sustainably generated at a higher scale level (Figure 12, 13 and 14).

The cluster as a whole will become a highly efficient complex with a constant daily use and bustling with life, both on weekdays and in the weekend. It will radiate a positive charisma affecting the whole neighborhood (Figures 15 and 16).

FIGURE 9
Step 01

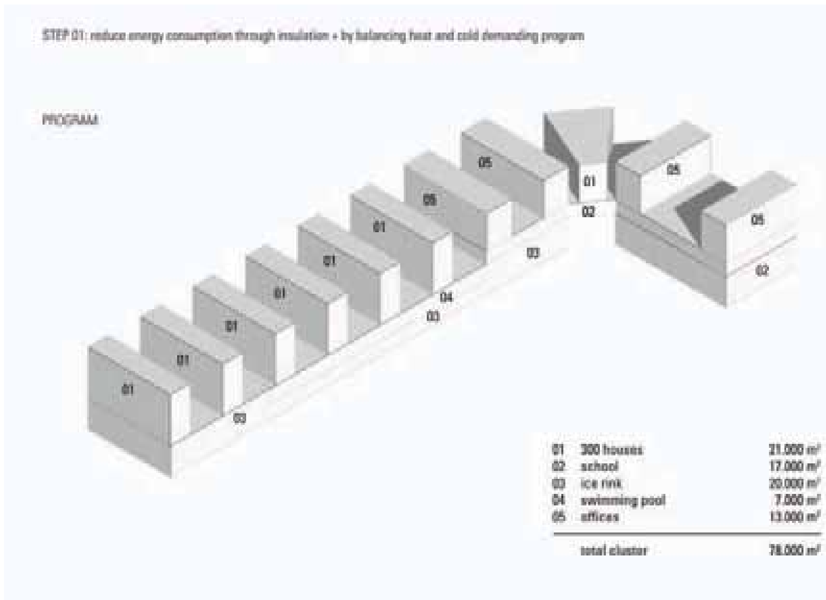


FIGURE 10
Step 02, for Summer

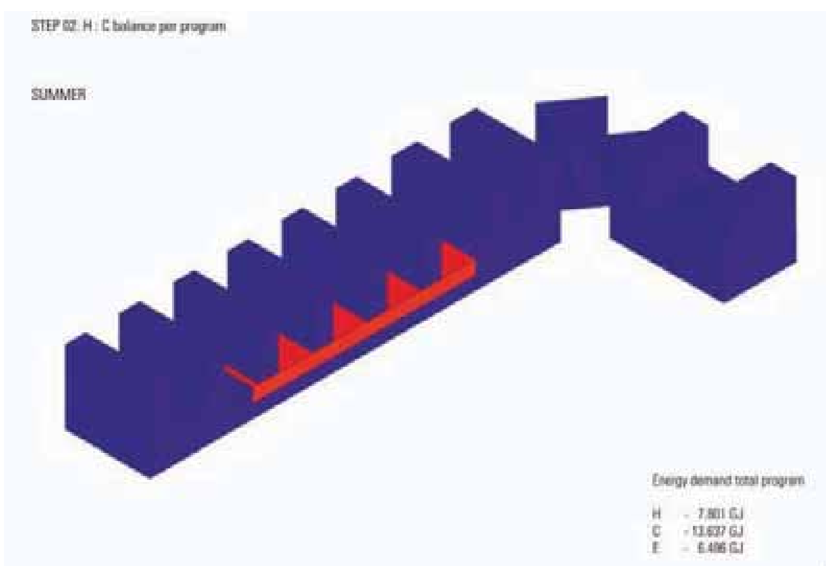


FIGURE 11
Step 02, for Winter

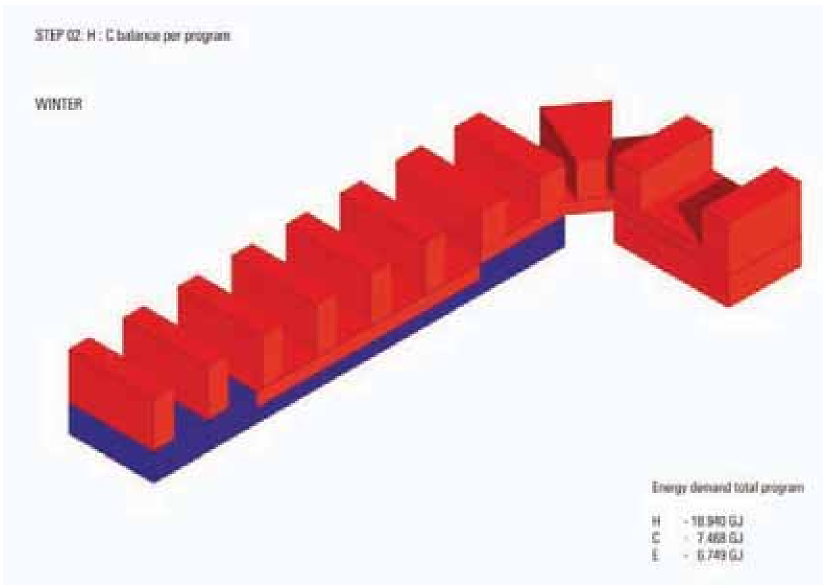


FIGURE 12
Step 03

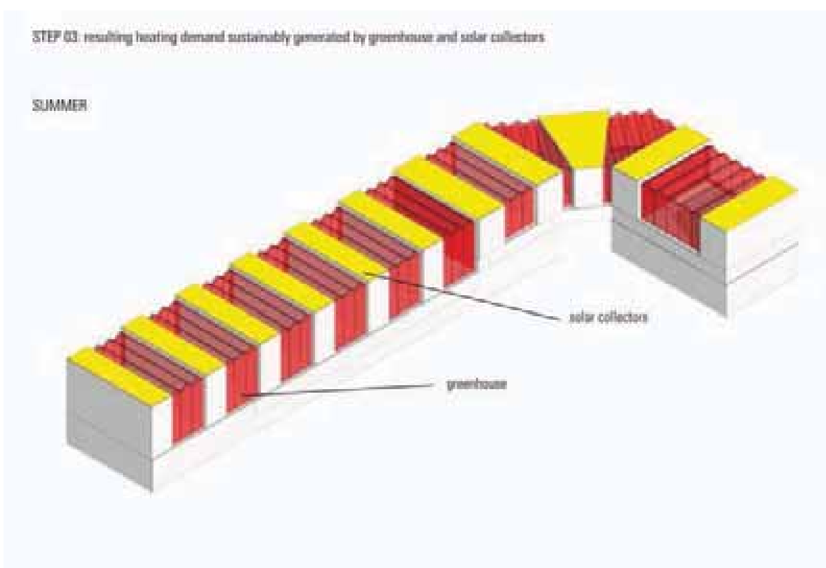


FIGURE 13
Energy Balance and Energy Demand

Step 01

Reduce energy demand through insulation + heat and cold demanding program in balance

total demand cluster:

H	- 26.741 GJ
C	- 21.106 GJ
E	- 13.245 GJ

Step 02

H : C balance total cluster

Heat - Cold ratio H : C
1:0,8

thermal storage coverd heating demand
21.106 GJ

resulting heating demand 5.635 GJ

Step 03

Resulting heating demand sustainably generated by greenhouse and solar collectors + renewable energy generation

H : C (dis)balance

contribution greenhouse 5.635 GJ

extra electricity demand due to usage greenhouse
563 GJ

ENERGY

contribution PV panels 1.761 GJ

resulting energy demand 12.047 GJ

demand:

H	0 GJ
C	0 GJ
E	- 12.047 GJ

FIGURE 14
Energy Flow Diagram

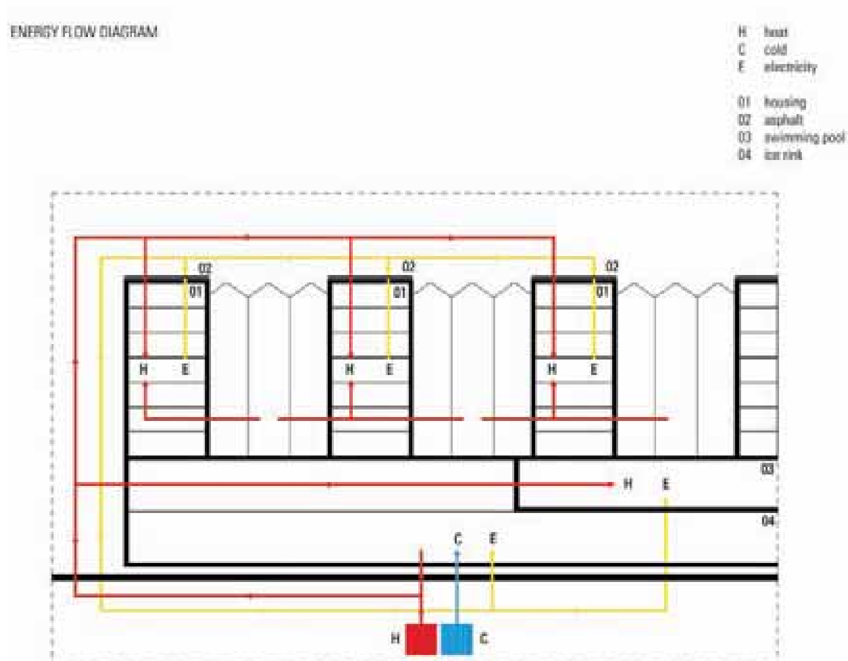


FIGURE 15
Programmatic Section

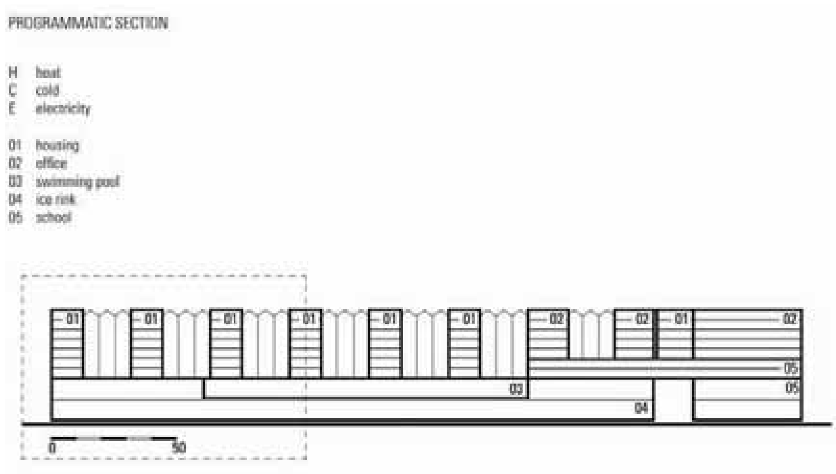
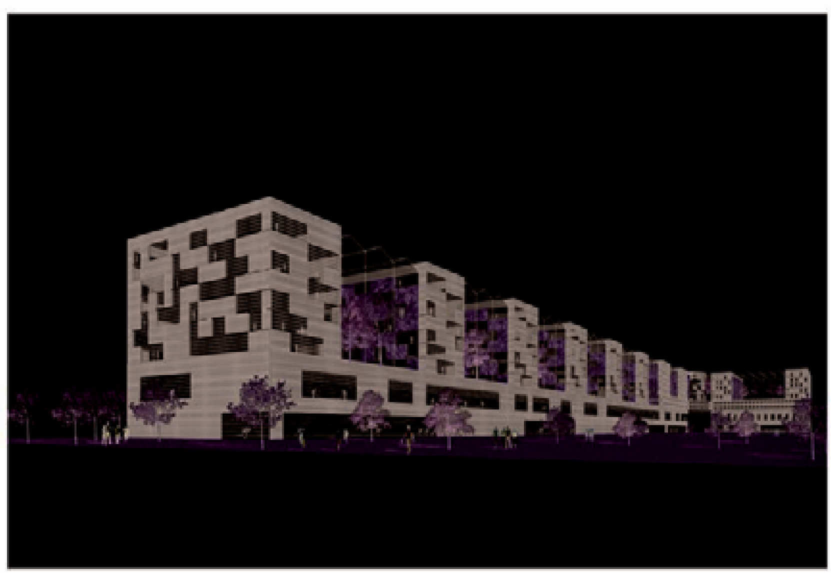


FIGURE 16
New Overall Plan with Mixed Program with Optimal Energy Exchange



4 CO_2 MAPPING

REAP provides a structure for CO_2-intelligent development of a particular area. If CO_2 issues are to play a role in spatial design and development then sufficient knowledge of the various possibilities must be available. At each step it must be clear what is actually feasible. The CO_2 map has been developed to provide such an insight. The CO_2 map gives a picture of the current situation and provides a toolbox for CO_2- intelligent developments for the area (Figure 17).

In reality the CO_2 map is much more than just a map. It is an instrument providing information for each aspect of REAP in the form of maps and background information. Aspects related to energy saving and renewable energy production are in the form of a geographical map coupled to a GIS-system. All aspects, in particular those related to energy exchange, are in the form of generic information concerning CO_2-intelligent opportunities.

The maps related to energy saving and renewable energy production (Figure 18) show the current potential at cluster level. There is an overview of which functions are present at each cluster. In addition, for each separate cluster the map shows how much energy could be saved and the amount of renewable energy that could be produced — heat and cold storage, urban wind, solar electricity and solar heat collection. Whereas the maps visualize the CO_2 -intelligent potential for the current situation, the toolbox gives guidelines for demolition, new building or additions to the program. Such new developments benefit from the generic information in the toolbox. It is even possible to modify the building program based on REAP and in particular on the information in the toolbox. For the first step the toolbox indicates the potential minimum energy consumption per m^2 — and thus the potential energy savings compared to the current situation — that is feasible for the different amenities. The generic information for the third step is an overview of the pre-conditions for the implementation of various forms of renewable energy production per building — heat and cold storage, urban wind, solar electricity and solar heat collection. The generic information in the toolbox for the second step is an overview of the consumption of electricity, heat and cold per m^2 for the different amenities.

This can be used to determine which functions can be combined energetically — demand and supply of heat and cold — for energy exchange within the program. It is also possible to determine whether it would be beneficial to incorporate an extra function in cases where the demand and supply do not match.

FIGURE 17
CO_2 Reduction, Energy Flows and Renewable energy [8]

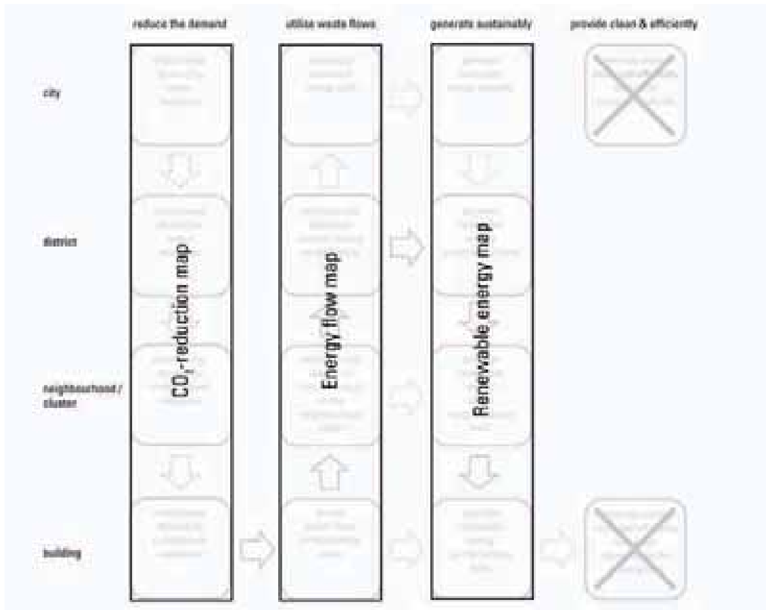


FIGURE 18
CO_2 Map with Reduction Potentials as a Result of Insulation and Other Existing Solutions [8]

5 CONCLUSIONS

The general aim of this study is to discover whether CO_2 neutrality can be achieved within an existing part of the city, working from the urban planning and spatial design processes. A manageable method is arrived at based on the guiding principle of reduction of both energy demand and CO_2 emissions. Further, REAP is based on a realistic approach to economic, social, political and organizational structures. The following points summarize the advantages and limitations of the REAP methodology in CO_2 neutral urban planning.

5.1 Other Architectonic Styles

The use of REAP has been worked out and depicted in areas and buildings (existing, remodeled and new) with a particular style. The REAP methodology is, however, architecturally independent and allows for different solutions – and the associated different architectural expressions.

5.2 Energy Techniques

An inventory of energy production on a city-wide scale shows that some techniques are potentially much more profitable than others. This, however, does not mean that the less profitable techniques are not useful in the development of individual buildings. Although it would appear that wind induced energy in an urban area is of little significance, an effective combination of high rise building and wind turbines is still possible. This, however, is beyond the scope of this study.

5.3 Financial, Economic and Organizational Aspects

Designs for the 2020s are based on the current (affordable) technologies. An in-depth study of financial-economic and organizational aspects goes beyond the scope of this report but a few recommendations can be made:

- Develop a joint sustainability target for a particular area together with instruments such as a sustainability index.
- Stimulate the different parties with benefits such as tax rebates to guarantee that targets are met.
- Ensure that the time factor is taken into account. The best (financial) solution for a particular situation changes with time.
- Develop new structures so that parties can attune energy supply.
- Develop new instruments to guarantee the delivery of energy.

5.4 Ideal Solutions Versus Time

The search for the perfect solution at the right place depends on different guiding factors — money, technology, organization, information — which all change with time. In the near future this can lead to a completely different solution to the one suggested in this study. Recently it has become increasingly clear that the choice of projects is mainly determined by economical considerations, together with the available energy techniques. Financially this depends on energy prices, availability of money and potential subsidies. This serves to underline the fact that there are no ideal solutions, at most they are only temporary; the best combination of measures is continually changing. Nevertheless it is essential to gather more information and gain an insight into the principles involved. When solving issues of renewable energy production, and in particular up-scaling production, it is essential to relate to each individual situation and the above mentioned aspects such as time and money. For each step in the REAP-methodology, it is useful to know which financial and organizational aspects are involved so that a well thought-out decision can be reached.

A critical note can be made regarding the new necessary infrastructure. As this is different from the existing energy infrastructure new investments have to be made. Also, carbon neutrality goes beyond heat and cold; in particular, the generation of sustainable electricity is difficult and has to be addressed. Apart from other issues which go beyond the scope of this article, as food and materials, mobility must be included. Radical changes in public and private transport are needed.

5.5 CO_2- Neutral Urban Development is Possible!

After applying REAP to Hart van Zuid, calculations have shown that CO_2 neutral urban development within the built up area of an existing city region is possible. That is why we, the authors, would like to encourage the reader to always consider where possibilities for small-scale energy exchange lie so that a gigantic effect can be achieved on a much larger scale.

References

Dobbelsteen, A. van den. 2008. "Towards Closed Cycles – New Strategy Steps based on the Cradle to Cradle Approach." In *Proceedings of PLEA 2008*. Dublin.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: Fourth Assessment Report*.

Jong, T.M. de (ed.), Moens M.J., Akker C. van den, and Steenbergen C.M. 2004. *Sun Wind Water Earth Life Living — Legends for Design.* TU Delft.

Lysen, E.H. 1996. "Trias Energetica — Solar Energy Strategies for Developing Countries." In *Proceedings of the Eurosun Conference.* Freiburg.

McDonough, W., and Braungart M. 2002. *Cradle to Cradle - Remaking the Way We Make Things*. NorthPoint Press.

Nickson, A. 2007. "Preparing London for Inevitable Climate Change." Presentation to the "Hot Places – Cool Spaces Symposium," Amsterdam, October 25, 2007.

Stremke, S., Dobbelsteen A. van den, and Koh J. 2011. "Exergy Landscapes: Exploration of Second-Law Thinking towards Sustainable Landscape Design." In *International Journal of Energy, 8(2), 148-174.*

Tillie, N., Dobbelsteen A. van den, Doepel D., Jager W. de, Joubert M., and Mayenburg D. 2009. "Towards CO_2 Neutral Urban Planning — Introducing the Rotterdam Energy Approach & Planning (REAP)." In *Journal of Green Building*. 4 (3): 103–12.

CHAPTER 9

Urban Sprawl and Climate Change: a Statistical Exploration of Cause and Effect, with Policy Options for the EU

Istvan Laszlo Bart*

Summary

This study provides a brief evaluation of the relationship between trends in transport emissions and urban land-use. It concludes that the growth of transport emissions is a result of specific urban planning and land use policies (or their absence). These policies can cause an increase in transport emissions even if the population size remains the same and there is no economic growth. This implies that governments need to implement sensible land-use policies. Such policies may not be very visible, but they have a huge impact on transport emissions.

Finally, the study outlines a few possible measures that could control transport emissions by addressing land-use issues. It explores ideas related to benchmarks, mandatory plans and the possibility of using the concept of emissions trading in connection with land-uses causing transport emissions.

Key Words: urban sprawl, land use, climate change, transport GHG emissions

*Corresponding author: istvan.laszlo.bart@gmail.com

1. CAUSES IN THE GROWTH OF TRANSPORT EMISSIONS — A STATISTICAL ANALYSIS

In 2005, transport emissions accounted for around 20 percent of all greenhouse gas (GHG) emissions in the EU-25. Road transport is responsible for 93 percent of all transport emissions (excluding international aviation and maritime transport), emitting about 900 million tons of CO_2 in the EU-27 in 2005. This is equal to almost half the amount of emissions covered by the EU Emissions Trading Scheme (ETS). Urban transport accounts for half of these emissions, a volume nearly equivalent to Germany's allowable annual emissions under the EU ETS.

Since 1990 transport emissions have increased by one-fifth in the EU-15, which is the largest increase among all emitting sectors. The trend in both the absolute and relative increase of transport emissions is not expected to change in the future. According to the EEA, by 2010 EU-15 greenhouse gas emissions from transport are projected to increase from the current 126 percent of 1990 levels to 135 percent if only existing policies and measures are used. Even with the recently adopted fleet average limit of 120 g CO_2/km for passenger car emissions, transport emissions would still increase an additional 27 percent over 1990 levels (EEA 2006).

The immediate cause of the phenomenal growth of transport emissions is clear: *a) People are travelling more and more* in general, and especially more on roads. In the EU-25, the number of road-passenger kilometres increased 26 percent between 1990 and 2000, i.e. much higher than the 20 percent increase in GDP in this period (OECD 2007). The number of cars has also increased by 35 percent in this period, approaching an average of 4 cars to 10 people in the EU-15. *b) Demand for the transportation of goods* (responsible for about a third of transport emissions) increased even faster in the same period, with the number of road-freight tonne kilometres growing by 36 percent (ibid.). This strong increase is somewhat mitigated by increased efficiency in fuel use, as CO_2 emissions from road transport have only increased by 18 percent.

The question then arises: what causes the increase in the transportation of passengers and goods? The current paper will look at the development of different general factors in EU Member States for the 10-year period between 1990 and 2000, and will assess their impact on road transport emissions through statistical analysis. Further, the analysis aims to determine a) whether there is a meaningful correlation between a particular indicator and road transport CO_2 emissions; and b) whether it is possible to establish a clear cause-and-effect relationship between this indicator and road transport CO_2 emissions. The analysis will cover population, gross domestic product (GDP) and the size of the area covered by human constructions, including buildings, roads and paved-over lots.

Technological improvements in vehicle efficiency are not considered as they are known to show a gradual and steady increase that is largely uniform in all Member States, and thus are unlikely to have a strong explanatory power (EEA 2009). The analysis will be restricted to road transport, leaving aside aviation, rail transport and shipping, together responsible for about than 30% of transport emissions[1]. Although growing fast, these transport modes are not yet much used in passenger commuting or in retail freight, and the relationship of their emissions to changes in the land area covered by buildings and roads is probably not relevant.

The analysis focuses on the relationship between changes in the above-mentioned variables and changes in road transport emissions for EU Member States where data is available. A simple linear multiple regression analysis is used to determine the correlation between the change in population, gross domestic product and artificial land area and the change in road emissions between 1990 and 2000. The method of analysis assumes that the same relationship holds true for all countries in Europe. The data analysed was expressed in terms of percentage change, so that the effect of the size of the countries would not appear in the analysis. The data used for the analysis is presented below (all graphs in the text are based on this dataset).

The analysis shows that the three variables explain to a considerable degree the variation in the increase in road transport emissions. The R^2 of the linear regression is 85.1%, the adjusted R^2 is 80.6%, and artificial land and per capita GDP variables are significant variables. Results of the analysis are presented in more detail below. If the insignificant population variable is left out of the regression, the R^2 is 84.7.4% and the adjusted R^2 is 82.0%

[1]This figure includes international aviation, and international shipping emissions (source: EEA GHG Data Viewer, www.eea.org).

TABLE 1
Change of Road Transport CO_2 Emissions and Possible Explanatory Variables Between 1990 and 2000 for Selected EU Member States

	Percentage Change Between 1990 and 2000			
Country	**Road transport CO_2 Emissions**[1]	**Artificial Areas**[2]	**Per Capita GDP**[3]	**Population**[4]
Austria	37.92%	3.06%	22.98%	5.08%
Belgium	20.85%	2.78%	*20.32%	2.85%
Denmark	15.77%	4.31%	24.42%	3.86%
France	17.80%	4.84%	16.42%	4.13%
Germany	10.57%	5.80%	18.90%	†2.72%
Greece	25.68%	13.82%	*19.34%	8.21%
Hungary	6.04%	1.51%	†24.20%	-1.57%
Ireland	106.30%	30.67%	*82.99%	8.19%
Italy	17.65%	6.13%	16.58%	0.80%
Netherlands	24.46%	22.42%	28.21%	6.52%
Poland	11.60%	1.44%	*44.09%	0.59%
Portugal	85.20%	38.64%	*29.92%	3.61%
Spain	46.45%	25.14%	*27.69%	3.64%
United Kingdom	6.42%	1.87%	24.83%	2.88%
Total of these countries	**18.59%**	**6.62%**	**26.82%**	**2.86%**

*using OECD's estimate for 1990 per capita GDP value; †using 1991 value instead of 1990

[1] Based on data from OECD and the European Environmental Agency

[2] CORINE Land Cover Database (European Environmental Agency)

[3] Real gross domestic product (expenditure approach), per head, US $, constant exchange rates (source: OECD)

[4] (source: OECD)

1.1 Population

As more people travel more and also demand a greater quantity of products to be transported, there is a clear cause-and-effect relationship between road transport CO_2 emissions and population increases. By contrast, it would not make sense to suppose that the population is growing because people and goods are travelling more.

The overall population figures are fairly stable in Europe. Between 1990 and 2000, the population of the EU-25 has increased by less than 3 percent. The variation among countries is modest, with Ireland and Greece showing an 8.2 percent increase and Hungary a 1.5 percent decrease over the period.

FIGURE 1
Comparison of Road Transport CO_2 Emissions Increase and Population Increase Between 1990 and 2000

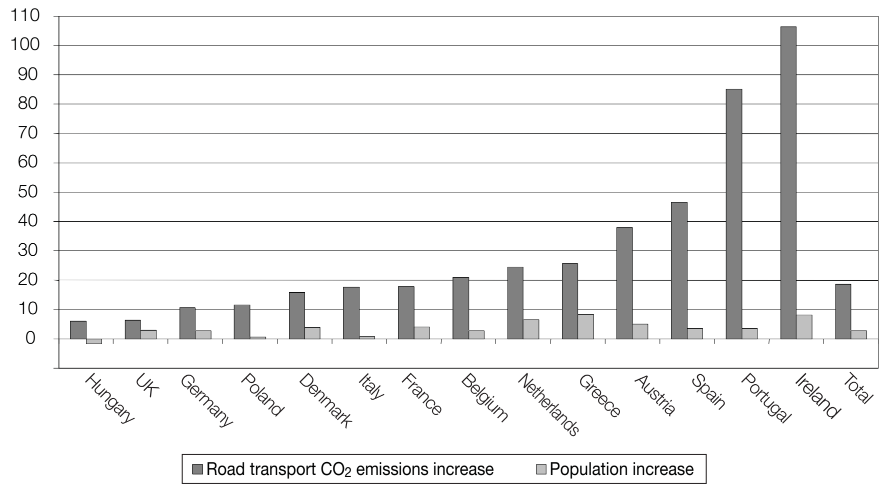


Figure 1 compares the growth of transport CO_2 emissions with population growth in selected countries. In some countries (e.g. Ireland), a higher than average population growth took place simultaneously with a strong increase of road transport-related emissions. For example, both Greece and Ireland experienced population increases of over 8 percent, but the growth of transport emissions in Greece was one-quarter of the growth seen in Ireland. At the same time, countries like Portugal and Spain have experienced an explosion in transport emissions while population increase remained slightly over the average[2]. It is also clear from multiple regression analysis that population growth in itself cannot explain the increase in transport emissions. According to the analysis, the growth of population does not contribute significantly to explaining the variance of the growth of CO_2 emissions. A multiple regression analysis of the relationship between road transport CO_2 emissions and population growth, per capita GDP growth, and increase of artificial areas yielded a t-value of 0.48 for population growth, and a p-value of 0.63.

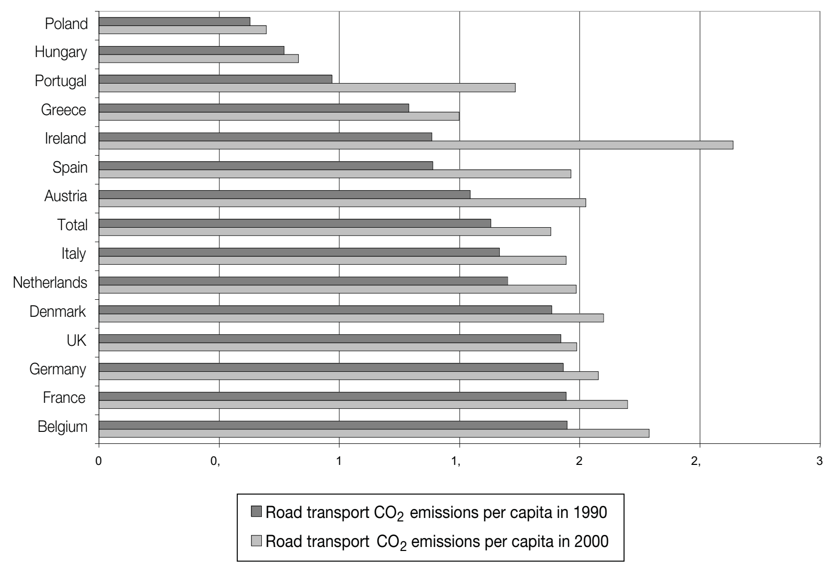
The lack of a strong relationship between population and road transport

---

[2]It should be noted however that while Spain and Portugal did not experience significant overall population growth, there is a very strong urbanisation trend in these countries, i.e. people are moving to the big cities. (See: page 15, EEA Report no 10/2006). This movement in itself does not inevitably lead to increasing transport emissions — it does so probably because new urban areas are built in a sprawling, transport-intensive fashion.

CO_2 emissions is quite remarkable, as it means that roughly the same number of people are able to both travel more and consume more goods, which results in more transport emissions than before. While worrying with respect to future emissions, the lack of such a strong relationship might be viewed positively, as it could mean that it is possible to reduce transport-related CO_2 emissions without limiting the number of people.

FIGURE 2
Road Transport CO_2 Emissions Per Capita in 1990 and in 2000 (tons)



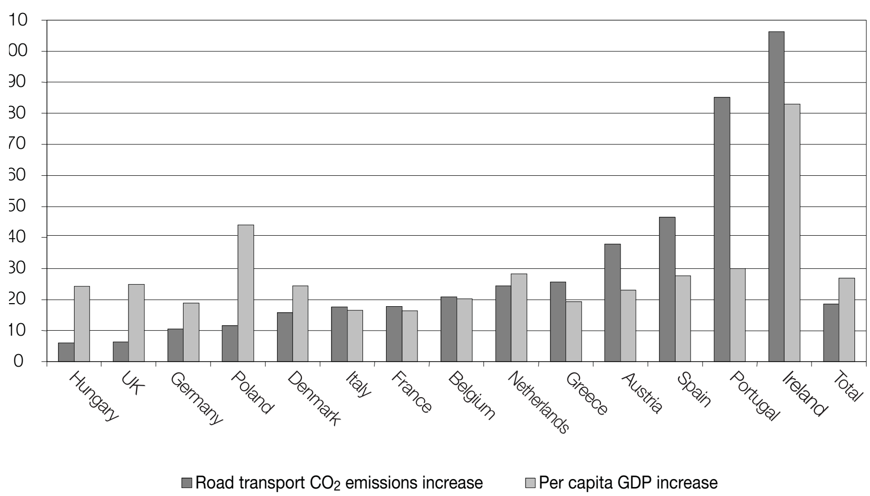
1.2 Gross Domestic Product

It is a general public assumption that the volume of transport and thus road-transport CO_2 emissions are related to GDP, i.e. the richer a country is, the more transport would take place. However, the cause-and-effect relationship between the two is not straightforward. It is sensible to suppose that people are becoming wealthier and, therefore, travel more and buy goods with a greater value (acquired through more transport). It is equally sensible to suppose that more transportation of goods and people induces a productive economy and generates more

GDP.[3] Therefore, GDP-growth and the growth of transport emissions are not necessarily in a one-way cause-and-effect relationship, but rather, may influence each other.

In the EU as a whole, transport-related CO_2-emissions have grown in tandem with per capita GDP. This statement masks great differences among Member States as to what extent GDP growth was coupled with growth in transport emissions. In some Member States the link is strong, whereas in others, it is almost non-existent. Figure 3 compares the growth of per capita GDP with the growth of road transport-related CO_2 emissions. As shown, some Member States have experienced high per capita GDP growth coupled with high growth in road transport-related CO_2 emissions (Ireland), but other Member States had enormous growth in road transport-related CO_2 emissions while per capita GDP growth was only slightly above average (Portugal, Spain). Finally, some countries attained an average per capita GDP growth with relatively little increase in road transport-related CO_2 emissions (UK, Poland, Germany).

FIGURE 3
Comparison of Road Transport CO_2 Emissions Increase and GDP Increase Between 1990 and 2000



[3]The fact that a growth in transport infrastructure investment induces economic growth has been supported by early works by e.g. Aschauer (1989), but recently several authors have refuted this claim. Crescenzi and Rodriguez-Pose (2008) have conducted an analysis of data for European countries which shows that although good infrastructure endowment is a precondition for high economic performance, additional investment in infrastructure is disconnected from economic performance.

The multiple regression analysis showed that per capita GDP contributes little to explaining the growth of CO_2 emissions. A multiple-style regression analysis of the relationship between road transport CO_2 emissions and population growth/ per capita GDP growth/ Increase of artificial areas yielded a t-value of 2.7 for per capita GDP growth, with a p-value of 0.02. If the insignificant population variable is left out of the analysis, the t-value is 2.9 and the p-value is 0.01. The coefficient of the variable is 0.6, which means that a 1% rise in per capita GDP produces less than 1% rise in transport CO_2 emissions.

This shows that road transport emissions are linked to economic growth only to some extent. If the cause and effect relationship shows that transport is a precondition of economic growth, one might conclude that the only way to limit growth of road transport emissions is to limit economic growth, which would be very difficult for any elected government to sell. A further analysis of transport-related CO_2 emissions and economic growth may reveal that some stages and types of economic growth do correlate with rising emissions while others not.

In wealthy countries where the motorway network is already built, with little space for new roads and high levels of car ownership[4], further economic growth may not necessarily be linked to greater transport volumes (UK, Sweden), and transport emissions could increase slowly over a high base level. In countries where the motorway network is in the process of being built and many people cross the wealth threshold necessary to buy a car, economic growth may be accompanied by a massive increase in transport emissions from a lower base level[5] (Portugal, Ireland). Such detailed analysis is beyond the possibilities of the present paper, however.

1.3 Increase in Areas Covered by Buildings

If population growth and economic growth cannot explain growth in transport emissions, other causes can be considered. Transport emissions increase because there is a greater quantity of passenger-kilometres and freight tonne-kilometres. The increase in these values could be a result of more passengers and goods travelling between the same destinations or of the same amount of passengers and goods travelling between destinations that are further apart from each other.

---

[4]For a comparison of GDP levels and the number of vehicles, see European Environmental Agency, *Indicator fact sheet* TERM 2002 32 AC — Size of the vehicle fleet, page 7. (http://themes.eea.europa.eu/Sectors_and_activities/transport/indicators/technology/TERM32,2002/TERM_2002_32_AC_Size_of_the_vehicle_fleet.pdf)

[5]This hypothesis seems to be borne out by the fact that the land used for road networks has indeed increased by over 300 percent between 1990 and 2000 both in Portugal and Ireland, while the average increase in the EU-25 was only 21 percent (EEA Corine Land Cover Database). In this period, Ireland had much higher than average economic growth, while Portugal's growth was only average.

For both goods and people, most journeys either connect two urban areas or connect two destinations within the same urban area. No reliable statistical data is available on how much of road transport CO_2 emissions is generated in urban areas. According to the EC's Green Paper on Urban Transport,6 "Urban traffic is responsible for 40% of CO_2 emissions … arising from road transport."

It would require a very complex analysis to fully map the long-term evolution of trip-lengths and destinations for all passengers and goods. In the following, this complexity will be minimized by assuming that the increase in road transport emissions can be explained by the increase in urban areas. An increase in urban areas increases individual trip lengths, and as most newly urbanised areas are fully car-dependent with no public transport, these areas would have to lead to increased road transport emissions. This assumption is well grounded in the findings of researchers (see e.g. Camagni et al. 2002).

While this approach does not fully explain the increase in emissions that occur in interurban transport, (i.e. about 50 percent of road transport emissions), it could provide a strong explanation for the increase of emissions within urban areas, i.e. for the other half of the emissions, because of the clear cause-and-effect relationship between destinations and transport emissions. As people and goods rarely travel to an empty field in the hope that one day they will find a house, a shopping mall or a factory there, the establishment of a destination (and the road leading to it) *always* precedes the journeys that cause the CO_2 emissions. Indeed, Southworth (2001) considers the building of new roads and buildings to be a primary reason for the growth in road transport.

For analysing the increase in urban areas, the CORINE Land Cover Database was used, which uses satellite imaging to calculate the number of hectares covered with a particular land-use type. CORINE uses about twenty different land-use classes, covering different types of natural areas (forests, agriculture, wetlands, etc.) and artificial areas (continuous and discontinuous urban fabric, commercial areas, transport infrastructure areas, etc.). Data is available for 1990 and 2000 for the EU-27, except Sweden, Finland, Cyprus and Malta. To measure the increase of urban areas, CORINE's composite land-use class of artificial areas is used. This composite includes all buildings and all transport infrastructure (with the latter being overwhelmingly roads), and in this paper this group will be referred to as "artificial areas".

An EEA report[7] provides a detailed analysis of the urbanisation and sprawl trends in Europe for the 1990-2000 period. According to the report, most European regions are sprawling (i.e. urban areas are expanding much more than population growth), as new housing and commercial development is almost

[6]COM(2007) 551 final, Green Paper: Towards a new culture for urban mobility, Brussels, 25.9.2007, p. 3.

[7]Urban sprawl in Europe, the ignored challenge, EEA Report No 10/2006

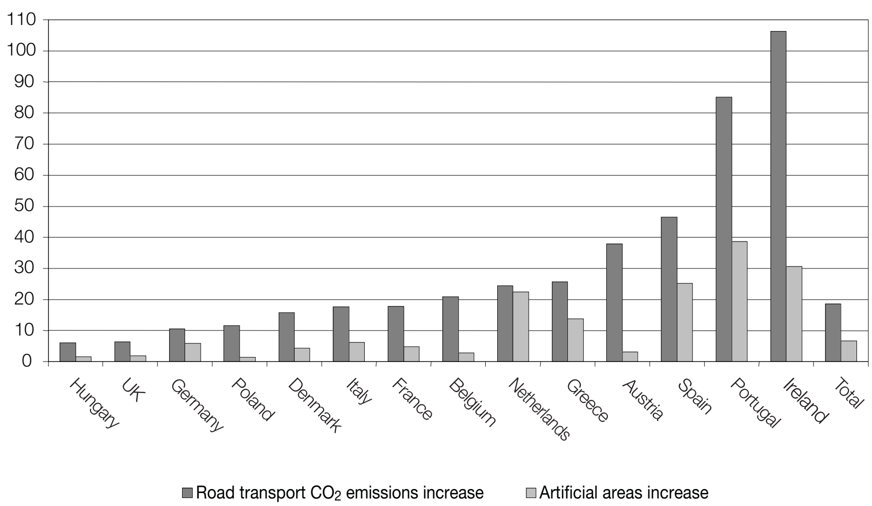
exclusively suburban and car-centric. As these areas are usually not new cities, but rather outlying appendages to existing urban areas, the inhabitants continue to use the same city centres, but reach them from further away. With the new areas usually not planned around public transport and too sparsely populated to be able to support effective public transport, the passenger car remains as the sole feasible mode of transportation. The area gobbled up by European cities between 1990 and 2000 is equivalent to the entire area of Luxembourg. The advance of artificial areas is alarmingly fast in Spain and Ireland, while the process is only beginning in the new Member States. A very important finding of the report is that sprawl is not a natural phenomenon; it can be effectively controlled with the appropriate government policies. Indeed, a study by Cameron, Lyons and Kenworthy (2004) concluded that *"a number of cities in Europe (e.g. Munich and Stockholm) and Asia (e.g. Hong Kong and Singapore) have shown that clear policy initiatives can contain the growth of urban private motorised mobility"* and *"in other cities such as Stockholm, the control of urban sprawl … appears to have been pivotal in reducing the growth of car use, despite strong growth in affluence and car ownership."*

The question is whether the expansion of artificial areas (in short, sprawl) can be considered as a driver of transport emissions growth. The multiple regression analysis which was conducted on the change in road transport emissions between 1990 and 2000 also included the change in the land covered by artificial areas as an explanatory variable. The result is that the relationship between the growth of artificial areas and the growth of transport CO_2 emissions is very strong, much stronger than for the other examined factors (i.e. population growth and per capita GDP growth). A multiple-style regression analysis of the relationship between road transport CO_2 emissions and population growth/ per capita GDP growth/ increase of artificial areas yielded a t-value of 4.2 for increase of artificial areas, with a p-value of 0.002. If the insignificant population variable is left out of the analysis, the t-value is 5 and the p-value is 0.0004. The coefficient of the variable is 1.6, which means that a 1% rise in artificial areas produces a greater than 1% rise in transport CO_2 emissions.

This result is in line with several studies that have found a strong link between the density and form of urban development and the amount of private car transport that the development entails (Newman and Kenworthy 1999; Handy 2005). In a particular example, Muñiz and Galindo (2005) reached a similar conclusion in their study of Barcelona when they stated that "*measures of urban form typically used (net population density and accessibility) have a greater capacity to explain municipal ecological footprints variability than other factors, such as average municipal family income and the job ratio, which leads the authors to conclude that urban form exercises a clear effect on the ecological footprint of transport.*"

Figure 4 provides a percentage comparison between the increase of artificial land and road transport emissions, as was done earlier for population and per capita GDP. The rate of sprawl experienced by individual Member States is widely divergent. It has barely started in the new Member States, while reaching dramatic proportions in Spain, Portugal and Italy. However, where sprawl is strong (e.g. artificial areas have increased by more than 5 percent from 1990 to 2000), a significant increase in road transport emissions is also found (with the exception of the Netherlands). Similarly, the increase in road transport emissions was the lowest in the countries experiencing the least degree of sprawl.

FIGURE 4
Comparison of Road Transport CO_2 Emissions Increase and Artificial Areas Increase Between 1990 and 2000



1.4 Summary

The strong correlation between increases in artificial land area and transport-related CO_2 emissions indicates that policies limiting the increase of artificial land could be effective in limiting the increase of CO_2 emissions in transport. Policies limiting land use will not necessarily restrict economic growth, for growth is not correlated to increasing the quantities of artificial land.

Sprawl is not an inevitable consequence of economic growth, but rather a result of specific government policies. The economy of the Netherlands and Portugal increased at about the same rate between 1990 and 2000, but Portugal saw both its urban area and transport CO_2 emissions grow at triple the rate of the Netherlands. This difference can probably be best explained by different land-use policies. Another example is the UK, which had strong economic growth in this period but only limited expansion of artificial areas, probably due to its vigorous policies against sprawl. According to Couch and Karecha (2006): "*urban sprawl in Britain is brought under strong planning control and this has been particularly effective in the large northern conurbations such as Liverpool*." As the newly urbanised areas are a primary cause of increasing transport CO_2-emissions, the current insouciance of EU policies towards increasing sprawl is a dangerous position that threatens to undermine the achievements of other climate policies.

The CO_2 emission effects of unmitigated sprawl are already clearly visible in the Mediterranean Member States. For example, although under the EU burden sharing agreement Spain is allowed to increase its total greenhouse gas emissions by 15 percent compared to 1990 levels by 2008-2012 , in 2005 its total emissions stood at 50 percent over the base year. Though emissions from all sectors are growing, transport emissions have almost doubled in Spain and have increased their share in total emissions. The picture is similar in Portugal, Ireland, Greece and Italy. The Member States most affected by sprawl are among those that are furthest away from meeting their Kyoto Protocol reduction targets.[8] All these countries will now have to spend huge amounts of money on buying credits to comply with their Kyoto target. Their transport emissions, engendered by growing affluence that allows more and more people to have cars, coupled with a lack of urban planning, will be very costly to reduce.

For better or worse, Central Europe always tried to follow the development patterns of Western Europe. This seems to be the case in transport development too. Greenhouse gas emissions from transport in the new Member States have increased by 28 percent between 1990 and 2004[9], which is higher than the average increase in the EU-15. As these countries have already fulfilled their Kyoto targets, no outside pressure will limit the growth of transport CO_2 emissions in these countries until after 2012. Due to the lack of roads and money for cars, sprawl was not strong in the land use patterns of the 1990-2000 period in these countries. However, as they are in the process of passing the wealth threshold which enables nearly everyone to buy a car[10], it is expected that transport emissions and sprawl will explode in the same way as they did in the Mediterranean. With no EU-policies against sprawl, the deluge of structural and cohesion funds (a

---

[8] EEA 9/2006, p. 20.

[9] EEA 9/2006, p. 23.

[10] The threshold appears to be being passed in these years. Car sales in Central and Eastern Europe have increased by 13.4% between 2006 and 2007, with several countries showing growth over 25%. http://www.jato.com/Documents/PRESS%20RELEASES/Central%20and%20Eastern%20European%20car%20market%20continues%20significant%20growth%2025.9.2007.pdf

large portion of which is spent on new roads) will only exacerbate this process. According to an EEA report: *"The new Member States seem to be repeating the experience of Ireland, Portugal and Spain. Starting from a relatively low transport level, all these countries experienced strong growth in transport and its greenhouse gas emissions due to high economic growth."*[11]

In order to prevent the further deterioration of the situation in the Mediterranean and to try to set new Member States on a more sustainable course of growth, the EU should get into the business of regulating city development and urban planning. The possible policy options are outlined in the next chapter.

2 WHAT COULD THE EU DO TO LIMIT THE GROWTH OF GREENHOUSE GAS EMISSIONS FROM TRANSPORT?

2.1 Current Policies on Reducing Transport Emissions

Existing and planned specific EU-level policies aim primarily at increasing the CO_2-efficiency of existing traffic volumes. Both the Directive 2003/30/EC on biofuels and the planned target of 120 g CO_2/km for new passenger cars by 2012[12] would bring substantial savings in transport-related CO2 emissions, but will only slow their growth and not stop the increase. The average carbon dioxide emissions of new passenger cars were reduced from 186 g CO2/km in 1995 to 163 g CO_2/km in 2004, representing a reduction of about 12 percent.[13] However, in the same period, 21 percent more cars were sold, more than offsetting the emission reductions due to increased CO_2-efficiency.[14] As nothing indicates that the trend towards a growing automobile fleet (and a parallel increase in the growth of artificial land[15]) would stop in the future, a similar offsetting of the planned policies can be expected.

The EU's Green Transport package of July 2008[16] makes an important step by providing a common framework for Member States' policies on charging for road usage by heavy lorries, and crucially, allowing the introduction of environmental

---

[11] EEA 9/2006, p. 23.

[12] Commission Communication - Review of the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles (7.2.2007, COM(2007)19 final)

[13] COM(2007)19 final, Impact Assessment, pp. 7, 32.

[14] EEA 9/2006, p. 47.

[15] Not surprisingly, there is a discernible correlation between the increase of the number of passenger cars and the increase of the artificial land area. In statistical terms: R^2(indicating the strength of the relationship) = 0.7 (1 means a perfect correlation, 0 means no correlation); P-value (indicating statistical significance) = 0.00000840912 (i.e. there is a 0.0008% likelihood that the correlation is "false")

[16] For a summary of the documents in the package, see: http://ec.europa.eu/transport/greening/index_en.htm

costs in the charges, something that was not possible previously. However, as the Communication[17] in the package states, *"Private transport is not covered because of subsidiarity"*. In other words, the EU does not consider itself legally empowered to introduce road charging for passenger cars, a policy that could have dramatic effects on sprawl and its related emissions.

Outside actual legislation, the notion that unsustainable land-use patterns are a main cause of the increase in transport emissions does appear in policy documents, though without offering policies to address the problem. The EU's Thematic Strategy on the Urban Environment[18] (Thematic Strategy) does at one point say that "*Avoiding urban sprawl through high density and mixed-use settlement patterns offers environmental advantages regarding land use, transport and heating contributing to less resource use per capita.*[19]", but it never quite makes the link between land-use decisions and climate change. [20]

A very useful result of the Commission's work on the Thematic Strategy is the development of guidance on Sustainable Urban Transport Plans[21], which provides a wealth of information on what local governments can do to reduce CO_2 emissions from transport if they have the resources to address the issue. The Annex of the guidance[22] provides detailed policy options in the areas of land use and transport planning co-ordination, traffic calming, fostering cycling and walking, promoting public transport, road pricing, and parking management.

The Green Paper on Urban Transport is a document that is up to date with the latest thinking on the environmental impacts of car-traffic and identifies sensible policies to promote the use of public transport, cycling and walking. In particular, it recognises that *"The trends towards suburbanisation and urban sprawl lead to low-density, spatially segregated land use. The resulting dispersal of home, work and leisure facilities results in increase transport demand. The lower densities in peripheral areas make it difficult to offer collective transport solutions of a sufficient quality to attract substantial amounts of users.*[23]" In other words, sprawl cannot be "fixed" by investment in public transport; it is an inherently climate-unfriendly mode of urban development, which cannot be eliminated by better transport policies. The problem of sprawl requires better land-use policies. However, the Green Paper on Urban Transport does not go beyond asking the question: "How can better coordination between urban and interurban transport and land use planning be achieved?[24]"

---

[17] COM(2008) 433 final, Communication from the Commission to the European Parliament and the Council on Greening Transport, Brussels, 8.7.2008

[18] COM (2005)718 final, Communication from the Commission to the European Parliament and the Council on a Thematic Strategy on the Urban Environment; Brussels, 11.1.6.

[19] COM (2005)718 final, p.10.

[20] COM (2005)718 final, p. 5.

[21] http://ec.europa.eu/environment/urban/pdf/transport/2007_sutp_prepdoc.pdf

[22] http://ec.europa.eu/environment/urban/pdf/transport/2007_sutp_annex.pdf

[23] COM(2007) 551 final, p.15.

[24] COM(2007) 551 final, p.16.

2.2 Possible Future Policies

From a policy development point of view, realising that sprawl is a main driver of the growth of transport emissions allows policymakers to do something beyond legislating CO_2 efficiency improvements that do not reduce the volume of traffic or hoping that modest increases in fuel tax would reduce emissions without causing public outrage first.

The growth of urban areas (at steady population levels) is not a desirable public good, but rather an undesirable consequence of ever greater fossil fuel-based mobility. Governments seek to limit sprawl, though with varying success. In the EU, as the Thematic Strategy states *"Most cities are confronted with a common core set of environmental problems such as poor air quality, high levels of traffic and congestion, high levels of ambient noise, poor-quality built environment, derelict land, greenhouse gas emissions, urban sprawl, generation of waste and waste-water.* [25]"

If greenhouse gas abatement policies are aimed at limiting sprawl, they can be expected to face less opposition than policies that directly limit car use or raise fuel costs. Unlike in the case of a road that people are not allowed or cannot afford to use, nobody complains about a situation where people do not need to travel to fulfil some need or other. Another advantage of concentrating on land-use policies is that the building of cities is already a densely regulated field, albeit the current objectives of regulations do not always include limits to greenhouse gas emissions.

The EU has significant limitations in developing policies on urban planning. Land-use policies are currently widely regarded as falling into national, regional or local competence, even though the climate change effects of urban planning do not justify this. Article 175 of the EC Treaty explicitly states that *"measures affecting town and country planning and land use"* require unanimity. These provisions also appear in Article III-234 of the Constitution; however, internal market-related harmonisation measures will be exempt from such unanimity requirements. Tax policies are in principle possible to adopt on an EU level, but they require unanimity. The EU's unsuccessful efforts in the 1990's to introduce a meaningful EU carbon tax suggest that fighting sprawl with EU-level taxes (either on fuels, vehicles or land-use types) is not possible in the foreseeable future[26], even though taxes could be very effective for this purpose.

As it is properly recognised by the Thematic Strategy, many European cities were successful in developing policies to halt sprawl and to limit the growth of transport CO_2 emissions. (Witness, for example, the outstanding success of the policies of Dutch cities to limit the growth of transport emissions compared to

---

[25] COM(2005) 718 final, p.3.

[26] For a short account of the EU's attempts to introduce a carbon tax, see Padilla and Roca (2004)

increase of land area in Figure 4.) However, as these policies are often locally initiated, only the vanguard of regional and local governments can implement them, while the majority of cities abandon themselves to the centrifugal forces of car-based urban development because of a lack of resources and/or expertise. Without central, EU-level requirements to address the problem of sprawl, most cities will only recognise it when it is too late. Bearing in mind the impending explosion of transport CO_2 emissions in the new Member States, the EC should not rely on the wisdom of local governments to recognise the need to fight against sprawl, but should rather focus on extending sustainable urban development practices through binding measures.

While there is a need for general EU-level policies in the field, it is very important to recognise the diversity of the myriad planning decisions that subsidiarity rightly places in the hands of local governments. Even so, EU policies could still be devised to avoid micro-management and concentrate on areas where it is possible to set up general guidelines that can be followed under all circumstances.

Following are a set of ideas on the types of instruments that the EU could develop with the purpose of reducing transport CO_2 emission through encouraging more sustainable land use patterns. The measures presented below were selected according to the following criteria: a) they are legal under the EC Treaty; b) they can be adopted on an EU-level without unanimity; c) they are not voluntary actions, but applicable for all. Ideas related to improving public transport are not included here as such measures are addressed in detail in the Green Paper.

2.2.1 Benchmarks, Targets and Minimum-Standards

Though urban planning needs to take account of diversity of urban areas, if the objective is to reduce CO_2 emissions, it is possible to develop overall objectives which could then be established as recommended benchmarks, future targets or mandatory minimum standards. The most straightforward would be a **public transport access requirement**, whereby Member States would be required to ensure that buildings have access to a certain level of public transport[27].

Though a public transport access requirement policy does not directly regulate urban development, the only way for Member States to realise such an obligation is (in addition to investing in public transport) through urban planning measures, in particular in requiring higher settlement densities. A public transport access

[27] A similar policy exists in the Netherlands since the early 1990s, known as the "ABC location policy", which differentiates between areas according to their accessibility by public transport. Businesses which attract a large number of customers can only be located at places with good public transport access. (http://international.vrom.nl/docs/internationaal/engelsesamenvattingnr.pdf)
Another comparable policy is the so-called "concurrency" policy in Florida and the US state of Washington, which requires local governments to only allow new urban development if certain public services (including e.g. public transport but also roads) is made available "concurrent with the impacts of such a development." (Southworth 2001; Steiner 1999)

obligation could stop the process of building low-density suburban areas where public transport is unable to compete with cars. As a minimum, the policy could extend to new apartments, larger workplaces and commercial establishments; it could then be extended to various categories of existing buildings. Similarly to recycling and renewables, the requirement could also be formulated in percentages to be reached within a timeframe[28]. A first step in this direction would be to include information on the level of public transport accessibility into all buildings' Energy Performance Certificates.

As a remnant of an age with different preoccupations, many cities have minimum parking-space requirements for new buildings. This policy is intended to make sure that relatively wealthy car-owners are also able to move into these buildings thus increasing the local tax base, but it invariably has the consequence of increased congestion. Therefore, instead of minimum requirements, targets for **maximum parking space requirements** should be established, depending on the level of public transport available[29]. Such a policy would reduce CO_2 emissions, reduce congestion and free up space for other uses. (Of course, this policy works only if the area is served by public transport or is accessible on foot and bicycle.)

Another possible benchmark is the designation of **peri-urban green areas** that could eventually form an effective urban growth boundary around large cities. Most large agglomerations have already expanded well beyond the administrative limits of the original city. Thus the frontier of sprawl is in suburban municipalities. While the central government of an agglomeration usually sees sprawl as problematic, many suburban municipalities welcome and foster sprawl on their territories because new development can increases the tax base. . A potential tool against this process would be to require Member States to designate no-development areas around large cities that would form a barrier towards sprawl and direct further development into existing transport corridors[30] and areas that are well served by public transport. Thus, such a policy is effectively the inverse of a public transport access requirement, in making areas not served by public transport off-limits to development. Unoccupied areas around cities are often agricultural areas that would not merit protection on the basis of their environmental value. Once such protected areas are established, they could also

[28] In its effects, such a percentage target could be compared to the UK target of building at least 60% of new housing on brownfields (i.e. previously developed land), which typically have better transport services than greenfields. (Couch and Karecha 2006)

[29] The Dutch "ABC" location policy is again a good example of this, as it maximises the amount of parking space that can be provided for each location type. E.g. in an "A" location the ratio of total area to parking area must not exceed 1:125.

[30] An example of this is the "Finger Plan" in Copenhagen, where development is restricted to the five "fingers" reaching out from the city. The fingers follow railway lines, and between the fingers, there are green areas. (see e.g.: http://www.geogr.ku.dk/dkgs/image/pub_pdf/artikler/2006_2/02.pdf)

serve the purpose of providing accessible green areas to people living in the city (which is necessary if they live at density levels that are high enough to maintain public transport.) According to Anas and Pines (2008), if charging for road usage is not possible, urban growth boundaries are effective second-best measures to limit sprawl.

2.2.2 Development of Mandatory Sustainable Urban Transport Plans

Short of targets and benchmarks, the public and authorities can consider the climate-change impacts of their development policies through a requirement to draw up plans and strategies on sustainable urban development.

A very important recommendation of the Thematic Strategy is for cities to develop **Sustainable Urban Transport Plans**. This is already an obligation in France and the UK, and other Member States are considering its introduction. According to the Thematic Strategy, "*Transport planning should take account of safety and security, access to goods and services, air pollution, noise, greenhouse gas emissions and energy consumption, land use, cover passenger and freight transportation and all modes of transport*.[31]" The guidance provided by the Commission on developing Sustainable Urban Transport Plans[32] is very useful for local governments who are already looking for solutions to the problems of urban land-use and transportation. However, without a specific obligation to draw up such a plan, many municipalities will not find the time and the money to prioritise urban transport and land-use planning. This is particularly true in those cities (particularly in new Member States) where these problems may not yet be endemic and the progress of car-based development could still be checked.

Transport planning by housing developers could be useful even if not coupled with a public transport access obligation. The Green Paper mentions in passing the possibility that "*developers could be encouraged to prepare a site-specific mobility plan as part of the procedure for obtaining planning permission*.[33]" In many countries, home buyers and local authorities alike tend to neglect the transport aspects of new housing developments. As the problem is similar to buyers' neglect or ignorance of their building's energy use, the solution could be to expand building energy performance certificates with information on the quality of transport services available at the building (and an estimate of the CO_2 emissions caused by the trips to the building.)

[31] COM (2005) 718 final, p.5.

[32] See footnotes 26 and 27 for links

[33] COM(2007) 551 final, p.7.

2.2.3 Emissions-Trading for Land Uses That Cause Transport Emissions (e.g. parking)

It is worth considering whether the transport emissions could not be limited through involving the land-use forms that cause emissions into an emissions trading scheme. Emissions trading would be superior to benchmarks or plans as it would be able to set a cap on transport emissions without prescribing the policies that should be used to achieve it.

Airplanes and ships are managed by commercial enterprises in fleets, where operators have many opportunities to increase carbon efficiency on a fleet level through better organization, and upgrades. By contrast, passenger cars are usually operated by private persons, who have little scope to improve the efficiency of their cars after the purchase. In the face of high carbon prices, the only immediately available emission-reduction option would be to reduce the amount of driving (on the longer term, the purchase of a more efficient vehicle or moving to a place with better transport options would also be possible.) Having only one short term option would probably make participants feel very constrained, thus reducing the acceptability of the scheme.

Emissions trading-induced increases in the cost of air travel may be countered with flying less or buying goods with lower transport costs. This is illustrated with the greater price-sensitivity of air transport compared to road or rail transport, as demonstrated in a meta-analysis by Kremers et al. Road transport thus appears to be a more essential service and/or one with fewer alternatives, than air transport. If people are less likely to give up road transport in the face of higher costs, many people will have no other choice but to pay more. This is both a social question and an issue of political acceptability.

To date, the inclusion of road transport into existing emissions trading schemes has not been possible for several reasons: a) the enormous number of transport vehicles make the management, verification and enforcement of a scheme involving individual car operators very costly; b) passenger cars are usually operated by private persons, who have little scope to improve the efficiency of their cars after the purchase. Thus, faced with high carbon prices, their only significant short-term emission-reduction option would be to reduce the amount of driving. Having only one option would probably make participants feel very constrained, thus reducing the acceptability of the scheme. Also, Incentives to drive less or to buy more efficient cars are much easier created through fiscal measures.

In order to make emissions trading a valid concept for transport emissions, a set of operators that are less numerous and can actively influence the CO_2-efficiency of the overall transport system is needed. For this, not only direct, but also indirect emitters need to be considered. Such indirect emitters could be the owners of houses or other buildings, but they are just as numerous as car operators, so the system would not be much simpler. A much more appropriate set of operators are the providers of parking spaces, private or public, or on a higher level of aggregation, municipal governments. According to Southworth (2001): "*Parking control policies, through either higher parking rates or restrictions on spaces available, offer considerable leverage through which to alter travel patterns.*"

Currently, free parking in out-of-town workplaces and shopping centres is one of the infrastructural bases of the present unsustainable trend of urban sprawl. As the Green Paper on Urban Mobility says: "*Providing more parking spaces may, in the long term encourage car transport, in particular if they are free of charge.*[34]" The amount of parking space is a significant limiting factor on the volume of transport, but it is often provided by private entities with no government control, thereby inducing further traffic and overloading the road network. The mechanism works in reverse as well, cars stop going to places where it is not possible to park. Therefore, controlling parking could effectively be used to control transport CO_2 emissions. Of course, such parking policies should always bear in mind that a total lack of access by car can result in the abandonment of an area, if the same amenities are freely available in other areas where cars can go.

A **trading scheme to reduce transport emissions involving parking place-providers** would work as follows:

i) The government would establish a total cap on the amount of transport emissions for a given period. A quantity of allowances equal to this cap would be distributed free of charge to entities or by auction.

ii) Entities responsible for a large number of parking (large offices, shopping centres, municipalities, etc) would be required to report the number of parking spaces provided, and they would be obliged to surrender a certain amount of allowances for each parking space.

iii) The amount of allowances to be surrendered per parking space would be set by the government in advance on the basis of average vehicle emissions, average trip lengths and average parking space occupancy rates. This figure should not be changed very often, and changes would need a long lead-time.

iv) As the surrender obligation for parking spaces is placed on the parking provider, the parking provider would need to obtain the allowances first, either through the free allocation or through a purchase in an auction or from another participant. The cost of an allowance (and thus, indirectly, the cost of providing a parking space) would depend on the level of scarcity, i.e. the size of transport emissions compared to the cap. Parking providers would have to decide whether to i) limit the amount of parking; ii) pass on the cost of purchasing allowances to their clients in the form of parking fees; or iii) to absorb these costs. Of course, the more parking is created, the greater the

[34] COM (2007) 551 final, p.6.

need for allowances and the higher their price would be, eventually forcing many parking providers to pass on the costs of parking.

It is important to realise that because parking spaces function in groups (i.e. one car needs a parking space at home, at the office and at the shopping centre to be able to operate) it is not necessary to introduce the system everywhere at the same time. The system would bring benefits even if first limited to large commercial establishments and offices (though questions of equity would arise as to whether it is fair to place the entire burden on a subset of parking space providers.) A great advantage of emissions trading for parking spaces is that there is no international competition and costs may be passed on to the consumer freely.

Beyond simply ensuring that the cap for transport emissions is not overstepped, and realising the polluter pays principle, such a scheme would have long term structural impacts. It would eliminate the cost-advantages of car-only locations, which are in fact free riding on publicly funded road infrastructure and take business away from more centrally located facilities which lack unlimited free parking. In the next step, if the accessibility by car of workplaces and shopping decreases, suburban living becomes more difficult, thereby inducing people to live in more sustainable locations.

A great political advantage of an emissions trading scheme for parking spaces is that it would not directly limit mobility by increasing the price of cars or the price of fuel, measures which would be very unpopular if implemented at a level which has a real effect on CO_2 emissions. The car fetish would be left untouched, and high parking prices would develop "automatically", without direct government involvement.

3. CONCLUSIONS

The statistical analysis shows that wherever sprawl occurs in the EU, it results in a strong increase of transport-related CO_2 emissions. Sprawl, measured in the increase of the areas covered by buildings and roads, is a stronger cause of increased road transport emissions than other possible causes, such as the growth of per capita GDP or population growth.

This conclusion is very relevant for the EU's climate policy. Unlike other sources of greenhouse gas emissions, emissions from transport are growing steadily. Current EU policies aimed at transport emissions try to increase the CO_2-efficiency of cars, but they are not enough to stop the growth of emissions. If sprawl is significantly correlated to increasing transport emissions, then the EU needs to adopt policies that try to limit sprawl. Several policy options are described in this paper, including a public transport access obligation, mandatory sustainable transport plans, and emissions trading for parking.

4. ACKNOWLEDGEMENTS

The author is grateful to Ágnes Kelemen for her assistance in the regression analysis, and to Gábor Ròna, Prof. Denny Ellerman, Peter Zapfel and David Delcampe for the ideas, comments and corrections provided for this paper.

References

Anas, A. and D. Pines. To be published in 2008. "Anti-sprawl policies in a system of congested cities." *Regional Science and Urban Economics* (doi:10.1016/j.regscurbieco.2008.05.001)

Aschauer, D.A. 1989. "Is public Expenditure Productive?" *Journal of Monetary Economics* 23 (2): 177–200.

Camagni, R., M.C. Gibelli, and P. Rigamonti. 2002. "Urban Mobility and Urban Form: The Social and Environmental Costs of Different Patterns of Urban Expansion." *Ecological Economics* 40: 199–216.

Cameron, I., T.J. Lyons, and J.R. Kenworthy. 2004. "Trends of Vehicle Kilometres of Travel in World Cities, 1960–90: Underlying Drivers and Policy Responses." *Transport Policy* 11 (3): 287–98.

Couch, C., and J. Karecha. 2006. "Controlling Urban Sprawl: Some Experiences from Liverpool." *Cities* 23 (5): 353–63.

Crescenzi, R., and A. Rodriguez-Pose. 2008. "Infrastructure Endowment and Investment as Determinants of Regional Growth in the European Union." EIB Papers, 13 (2): 62–101.

EEA (European Environmental Agency). 2006. *European Environmental Agency Report No. 9/2006, Greenhouse GasEemissionTtrends and Projections in Europe 2006*, 39–40.

______. 2009. Average Specific Co2 Emissions of New Passenger Cars per Fuel Type and Targets, (http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=2465)

Handy, S. 2005. "Smart Growth and the Transportation - Land Use Connection: What does the Research tell us?" *International Regional Science Review* 28 (2): 146–67.

Muñiz, I., and A. Galindo. 2005. "Urban Form and the Eological Footprint of Commuting. The Case of Barcelona." *Ecological Economics*, 55: 499–514.

Newman, P., and K. Kenworthy. 1999. *Sustainability and Cities – Overcoming Automobile Dependence*. Island Press, Washington, D.C.

OECD. 2007. Cutting Transport CO_2 Emissions: What Progress? http://www.internationaltransportforum.org/Topics/pdf/07CO2summary.pdf

Padilla, E., and J. Roca. 2004. "The Proposals for a European Tax on CO_2 and their Implications for Intercountry Distribution." *Environmental and Resource Economics* 27: 273–95.

Southworth, F. 2001. "The Potential Impacts of Land Use Change Policies on Automobile Vehicle Miles of Travel." *Energy Policy* 29: 1271–83.

Steiner, R. 1999. "Transportation Concurrency: Florida's Example, Transportation Research Record." *Journal of the Transportation Research Board:* 1685.

CHAPTER 10

The Role of Intelligent Transport Systems for Demand Responsive Transport

Robert Clavel,* Elodie Castex, Didier Josselin

Summary

Demand Responsive Transport (DRT) is a public transport system, which provides the user with the advantages of both public transport and taxi services. It was often considered as a marginal mode of transport reserved for areas with low population densities. Since the end of the 1990s, the numbers of DRT systems have been increasing consistently, with new investments in urban, suburban and rural spaces, and with varying degrees of operational flexibility. The flexibility and efficiency of DRT systems are influenced by several factors, the most important being technological. Most of these technological developments are in the field of Information and Communication Technologies (ICT). This paper illustrates the use of technology to improve DRT efficiency with two case studies from France (Pays du Doubs central and Toulouse). The type and level of ICT used is strongly dependent on the type of DRT service, its level of flexibility, and its specific optimization problem. The examples of Doubs Central and Toulouse, two different areas, show that technology can play a key role to optimize DRT trips and bring quality service to the population in a large area, or when the patronage is high. Technology offers the potential for achieving real-time demand responsiveness in transport services, particularly in complex networks, to a level far in advance of manual systems.

*Corresponding author: robert.clavel@gmail.com

1. INTRODUCTION

Originating in the mid-1970's, Demand Responsive Transport (DRT) services initially aimed at serving areas with low population density, and offered an alternative form of transportation to disabled people. Now DRT is also used in urban and suburban areas, and offers a large variety of services: ranging from transport for all types of passengers in regular commuting schedules but with low volumes of passengers, to transport for specific areas (airports, etc.). The development of suburbs and the dispersion of origins and destinations of trips led to the emergence of this form of public transport.

The general idea of DRT is to provide people with a public transport service when conventional transport services would be too expensive. DRT responds particularly to dispersed mobility needs, including hours of low demand, areas with low population, and target users dispersed among the general population (e.g. disabled, elderly, students, and tourists).

DRT is a flexible transport service, which adapts to the demand of passengers who have to book their trips. So DRT introduces an innovative approach to mass or collective transport, both in terms of service production and target population: the transport service is not provided on a fixed line but is offered over a defined area. The bus trips are not bound to a specific route or fixed timetable as in the case of conventional service, and the flexibility is provided by the capability to adapt the service to the level and characteristics of demand. Each trip is planned based on the user request in terms of start/arrival timing and origin/destination. In DRT services, the bus will reach the stops only when it is needed and at a pre-arranged times, avoiding long and useless waiting at stops by the users. It exists in the form of different types of services: door-to-door[1], fixed routes, fixed routes with deviations, free routes among a set of points[2] (Burkhardt et al. 1995; Ambrosino et al. 2004; Castex 2007). These services are more or less flexible depending on the public, the area and the goals of the service.

In different European cities and regions, many advantages and benefits are associated with DRT services that are complementary to conventional and scheduled public transport. One of the main reasons for the emergence and success of DRT services is the availability of different information and communication technologies (ICT). These have radically improved the possibilities to provide personalized transport services, in terms of interface with potential customers, optimization and assignment to meet travel requests, and service provision and management. The support of adequate ICT tools is particularly necessary for the management of user-booking volumes, number of trips, etc.

---

[1] "A service that picks up passengers at the door of their place of origin and delivers them to the door of their destination" (Burkhardt et al. 1995).

[2] e.g. stop-to-stop services.

This paper first provides an overview of existing DRTs in France, and subsequently demonstrates how technological opportunities can contribute to the management and development of DRT. Examples of the use of ICT for DRTs are provided for two case study locations in France.

2. STATE OF THE ART OF DEMAND RESPONSIVE TRANSPORT IN FRANCE

DRT in France is managed by transport authorities, which correspond to administrative divisions such as communes[3] and the county council. Sometimes an association or a private firm can also manage a DRT. In certain cases, a transport authority can manage several services of DRT, each "service" corresponding to one specific offer of transport located in a particular space.

A database of 650 DRT services in metropolitan France was established between 2003 and 2005 (Castex 2007). It includes a national census on the DRT (DATAR, DTT, ADEME, 2004; UTP, 2005), as well as information gained from websites or directly from the transport authorities. The objective of the database is to make an inventory of DRT services at the scale of the "service" and not at the scale of the "transport authority." This provides information on the evolution of DRT services and helps map them.

2.1 Increase in the number of DRT services since the late 1990's

In 2005, there were 615 DRT services, managed by 384 transport authorities, covering more than 7000 communes. Figure 1 presents the number of new DRTs services created each year and registered in the database. Their number has increased in France noticeably since the end of the 1990s. This growth was encouraged by several laws[4] oriented toward the better management of transportation systems in accordance with the needs of urbanization and environmental protection. DRT services are especially promoted in cities or in territories without transportation and offer a large variety of services. It is possible to distinguish different kinds of DRT according to their users targets. A majority

---

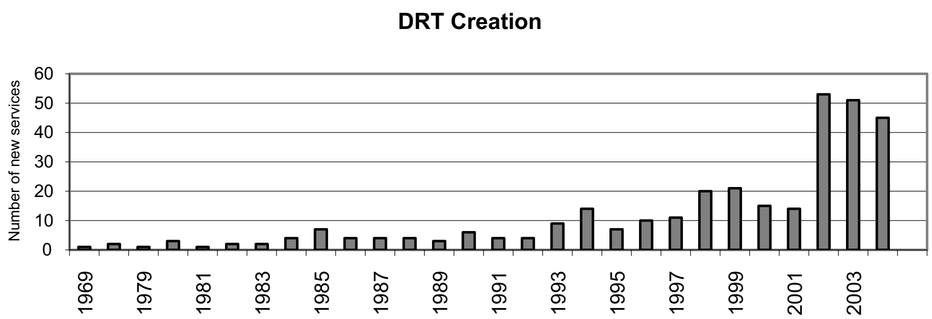
[3]The commune is the smallest administrative subdivision in France of which there are 36 000 in metropolitan France.

[4]The law of « orientation for national transport », dec. 30th, 1982 which establishes that the right of transport for everybody must be fulfilled, and defines DRT as a possibility for transport authorities

The law for »development of rural areas », Feb. 23rd 2005, which establishes that in case of lack of public transport services, DRT can be developped

The law for « equality of rights for disabled people » which establishes that specific DRT can be developped when regular lines can't be accessible to disabled people of DRT services provide transportation services to all the people like the other modes of transport (General DRT), while some services are dedicated to specific users like disabled people (Paratransit), customers of private firms (Private DRT), members of assocations (Social DRT), or railway users (TAXITER).

FIGURE 1
Number of New DRT Creations in France



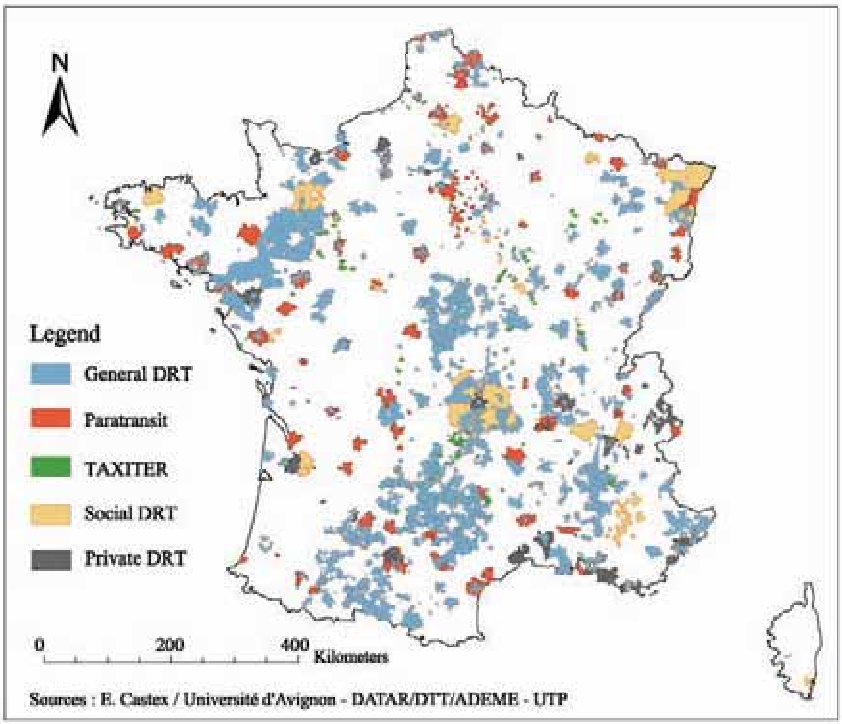
Source: Castex 2007.

2.2 DRTs services in France

Figure 2 shows that DRT services are scattered all across France. DRT services for all users (general *DRT*) are more numerous than the others, and a number of them are located in rural areas. Social DRT are widely common in rural areas, but serve relatively few people (only members of relevant associations). TAXITER is also used in rural areas where rail travel is not very common.

A lot of cities use general DRT in order to complete their transportation system. Typically, general DRT is used to serve the outskirts of the bus network or to take the place of bus routes during off-peaks hours or at night. It is also numerous in suburbs, where the transportation network is less efficient. The area with a presence of general DRT services represents only 15 % of the French territory but contains 50 % of the population. Most cities have also established the paratransit type of DRT service. Private DRT services exist only in the larger cities. The different types of DRT services, together, are present in 24.4 % of the French territory, which corresponds to an area where 90 % of the French population live.

FIGURE 2
Location of DRT in France

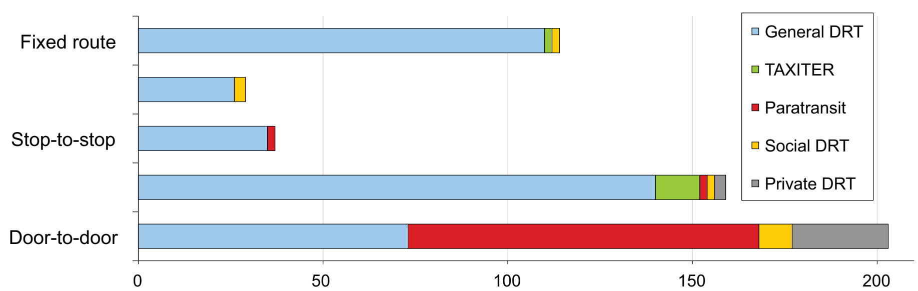


Source: Castex 2007.

DRT services also differ according to the nature of their supply or availability, which offer varying degrees of flexibility. *Door-to-door* DRT services impose the least constraints, with service characteristics comparable to that of a private car or a taxi. At the other end of the spectrum, *fixed route* DRT services can be compared to a bus line: the trip is predefined with given departure and arrival times. The other types of DRT services available offer intermediate forms of flexibility: *stop-to-stop* services permit free routes among a set of points, but their flexibility depends on the number of stops and their location; convergent DRT users have their arrival point predetermined but their departure point is unrestricted. These two kinds of DRT services are relatively similar to *door-to-door* services in terms of flexibility while *fixed routes with deviations* DRT services are less flexible and relatively similar in nature to *fixed routes DRT.*

Figure 3 shows that door-to-door systems are the most widely prevalent, especially with respect to services dedicated to specific users. Many general DRT services are convergent, i.e. their destination stops are predefined by the relevant transport authority, but fixed route DRT services are also numerous. Stop-to-stop services and fixed routes with deviations have been used less frequently in France, although their use is increasing with time.

FIGURE 3
Different Kinds of DRT in France



Source: Castex 2007.

2.3 Small-scale services

DRT services in France are mostly a set of small-scale initiatives, in terms of the scale of operations, and/ or the number of passengers carried. Indeed, the majority of services are located in smaller administrative areas. Some rural DRT services organized by county councils consist of larger operations, but they are in areas with low population density. DRT services in cities are usually located in the suburbs, where the population density is low too. Moreover, the spatial configurations of DRT services rarely correspond to the busiest commuter routes.

New technical innovations and solutions (both hardware and software) have been developed to make it easier to introduce applications to support demand responsive multi-modal public transport services. These innovations are primarily in the domains of vehicle-locating systems, communications and network, and they have generaly been developed for specific operators or functions. The main customers for such products are public transport operators, regional authorites and systems integrators, who seek a mix of technologies depending on the operational and financial strategies they wish to implement. Although some products have been developed for managing DRT services, they are few, and have not been tested widely. Therefore, there is a strong potential market for products to support DRT technologies.

For the future, DRT services should be enhanced to a wider scale to improve their efficiency, encourage technological innovations to integrate their functional requirements, and extend their services to areas with high levels of population density and more intense commuting requirements (e.g. during the office-time related rush hour). The purpose of large-scale DRT services is to offer a better quality of service, a competitive supply and to realize economies of scale (Tuomisto and Tainio 2005). They can also contribute positively to the environment by substituting for the use of private cars.

3. DRT SERVICES IN EUROPE

Several large-scale DRT services are available in Europe, e.g., *Flexlinjen* in Göteborg (Sweden), *Treintaxi* and *Reggiotaxi* in the Netherlands (Enoch et al. 2004), and *Drintaxi* in Genoa (European project CIVITAS[5]). Technological improvements have enabled these services to be relatively flexible in their supply characteristics. Technology in European DRT services, such as SAMPO, SAMPLUS, FAMS[6] (Enoch et al. 2004,) or CIVITASis used in travel dispatch centers, and for communications systems including those on-board. Several types of DRT user interface systems are used through different channels like phone, internet, and GSM/SMS.

SAMPLUS is a European project (1999) which has demonstrated and evaluated Demand Responsive Transport (DRT) services using telematic technologies at five sites in four different EU member states (Belgium, Finland, Italy, Sweden). This project shows that the level of ITS support for DRT is a critical factor. Unless an operator can confidently predict high patronage and can afford a major investment in hard and software, it is recommended that low to moderate technology solutions are developed. Large-scale investment is most likely to be possible in regulated market environments where more resources, including manpower, are easily available. SAMPLUS also shows that public transport users may regard DRT services as a means of improving intermodality and system integration, especially where there is no such pre-existing service, thus opening up mobility opportunities for all citizens and moving one stage closer to seamless public transport journeys. More specifically, DRT services can be tailored to suit the requirements of the local situation, whether through highly

---

5 http://www.civitas-initiative.org
it aims at supporting and evaluating the implementation of ambitious integrated sustainable urban transport strategies in european cities

6 DRT experimentations in Italy, Finland, Belgium, Sweden, England for citizens in rural and urban areas

flexible routing or by guaranteeing connections with conventional services. While it is not the objective of DRT services to adopt a dominant role in the provision of public transport, policy makers should regard it as a vital supplier of services where conventional solutions are untenable (e.g. in low demand areas for public transport). Thus, awareness raising should not only be directed towards local authorities and operators, but also towards central government institutions, which themselves exert considerable influence over the actions of local authorities.

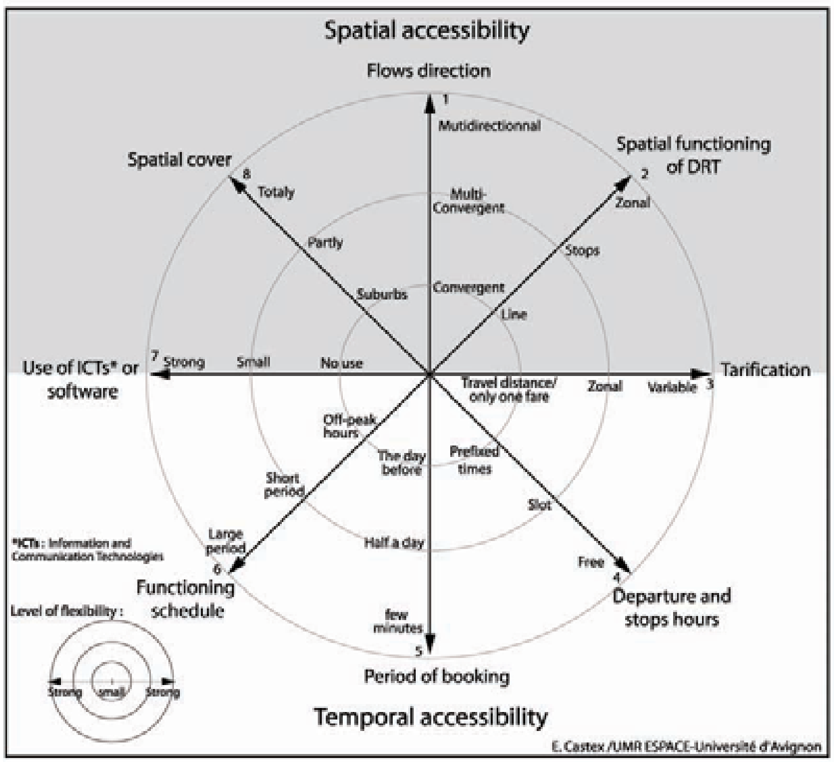
4. NEW TECHNOLOGIES TO ENHANCE THE FLEXIBILITY OF DRT SERVICES

Flexibility is an important characteristic for transportation modes. A private car provides strong flexibility in comparison to other modes of transport since it does not involve predetermined trip bookings, and allows for door-to-door trips with easy accessibility. However, in European cities its ease of use is now increasingly constrained by traffic jams and limited parking availability, especially in the city centers. Therefore, public transport systems are more efficient in these areas, although users criticize their lack of flexibility and the numerous connections to be made between them due to fixed itineraries. In more sparsely populated suburbs and smaller towns, the private car still offers the most effective mode of transport. DRT, which is an intermediate form of transportation between a private car and a bus, can provide services with a variable level of flexibility, the degree of variability depending upon the choices of the relevant transport authority.

4.1 Defining Flexibility with Respect to DRT Systems

Several factors influence the flexibility of a DRT service. These include prerequisites with respect to booking a trip, and the nature of the trip route. Figure 4 compares and evaluates levels of flexibility in DRT services. Each axis represents the main features that may influence flexibility in different modes of transport, which can also be applied in the context of DRT functioning. The placement of a DRT service at the center of the graph symbolizes a low level of flexibility, while an outward movement, away from the center of the graph, indicates greater flexibility. Flexibility is assessed in terms of temporal accessibility (represented in the bottom half of the figure), and spatial accessibility (represented in the top half of the figure, in grey).

FIGURE 4
The Eight Components of the DRT Flexibility



Source: Castex 2007.

For instance, in the top half of the diagram, the axis "direction of flows" indicates flexibility levels in trips opportunities available with a service. A DRT can have multidirectional flows (all trips are possible in a given area) or convergent flows (only trips toward a convergent point[7] are possible), with the first being more flexible. Multi- convergent flows represent intermediate levels of flexibility where several "convergent points" may be available. To the right of "direction of flows" is the axis representing the "spatial functioning" of a DRT: a service can have a zonal functioning (e.g. door-to-door), an organization based on stops (e.g. stop-to-stop services) or on lines (e.g. fixed routes, fixed routes with deviations). The "spatial cover" axis represents the fact that a DRT service

[7]A convergent point can be a railway station, a town or a shopping center.

can cover all the territory under the administration of a transport authority or segment of it. The above three axes together indicate the spatial accessibility of a DRT service. On the other hand, temporal accessibility is determined by:

- the flexibility of the departure and stop hours; they can be free, pre-determined, or limited according to time slots;
- the "period of booking" which varies from a few minutes to one day;
- the "functioning schedule": the DRT can offer services for a large duration of the day (e.g., 8 am to 7 pm), a relatively short duration (e.g., 10 am to 5 pm) or only during off-peaks hours.

Between these two axes (spatial and temporal accessibility) are located the components that depend on both time and space variables. Tariff systems can be based on time (e.g. variable tariffs based on peak and off-peak hours) or space (e.g. distance covered, or a zonal price). ICT or software use includes time and space dimensions too by permitting better trip management. Without them it is impossible to manage a flexible service in a large area, or one targeted toward a large number of users. Three levels of flexibility with respect to ICT use are represented in Figure 4: no use, minimal use, and strong use.

4.2 Description of Technologies Used for DRTs

The success of DRT services is due, in part, to the availability of different ICTs which have radically improved the possibilities to provide personalized transport services in terms of interface with potential customers, optimization and assignment to meet travel requests, and service provision and management. Continued advances in IT platforms (advanced computer architecture, web platforms, palmtops, PDAs, in-vehicle terminals, etc.) and in mobile communication networks and devices (GSM, GPRS, GPS, etc) have supported:

- DRT operators with respect to service model dimensions, including route, timing of services and vehicle assignment, and have enabled them to alter the service offered in response to current or changing demand;
- A more flexible evolution and use of the operational cycle of DRT services for both transport service operators and passengers. These have made easier aspects related to trip booking, user trip parameters, negotiation phases between the operator and the user, and communication of trip to drivers, service follow-up/location, reporting the completed service.

Usually, ICT-based computer architectures supporting DRT operations are organized around the concept of a TDC (Travel Dispatch Center). The TDC is the main technological and organizational component supporting the management of DRT service provisions. Computer architecture developed for DRT operations include the following:

- Several integrated software procedures to support the operations and management of DRT Travel Dispatch Centers. These include technological developments to ease procedures with respect to handling user requests, trip booking, service planning, vehicle dispatching, vehicle communications and location notification, system data management, and regular Public Transport notification;
- A communication system usually based on public or private long-range wireless telecommunication networks, supporting communication and information exchanges (both data and voice) between the TDC and the DRT vehicles;
- Several types of DRT user interfaces, enabling communication between the user and the TDC through different channels (i.e. phone, internet, GSM/SMS-Short Message Service, and automated answering devices – Interactive Voice Response (IVR) with Computer telephone integration (CTI));
- On-board systems (IVT — In Vehicle Terminal) installed on DRT vehicles to provide driver support functions during vehicle operations in the form of dynamic journey information, route variations, passenger information, and driver/dispatcher messages.

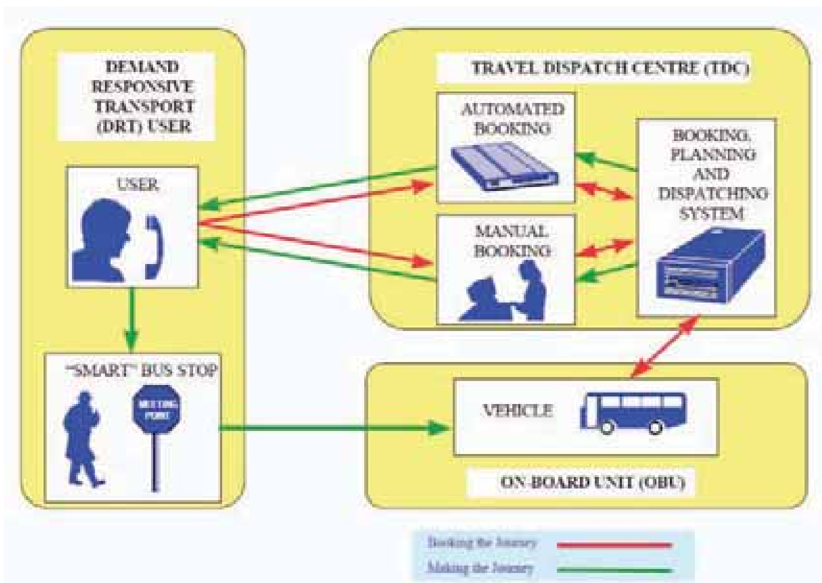
All existing DRT installations are realized through variations in the above basic computer architecture schemes, the implementation of which is made possible by a number of key enabling technologies. These include:

- Booking and reservation systems to manage customer requests;
- Regular public transport information (dynamic or static) meant for DRT operations that support regular public transport services, but also avoid conflicts of DRT schedules with regular public transport schedules;
- Web, Interactive Voice Response System (IVRS), Computer Telephone Integration (CTI); and hand-held devices to assist customer booking;
- Dispatching software for allocating trips and optimizing resources;
- Communication network to link the TDC with drivers and customers;
- In-vehicle units to support the driver;
- GPS-based vehicle location systems;

- Smart-card based fare collection systems;
- Management information systems, administrative systems, and other data analysis systems

The role of the TDC is important for the maintenance of system performance and service provisions (Figure 5). The optimized management of user requests through the TDC with the help of ICT also leads to a potentially more economically efficient model of DRT operations.

FIGURE 5
DRT Architecture



Source: Ambrosino 2004.

5. EXAMPLES OF DRT SERVICES USING SPECIFIC TYPES OF ICT

Provided here are two examples of DRT that illustrate the role of ICT for DRT management. The examples of Doubs Central and Toulouse, two different areas, show that technology can play a key role to optimize DRT trips and bring quality service to the population in a large area, or when the patronage is high. As noted, technology offers the potential for achieving real-time demand responsiveness in transport services, particularly in complex networks, to a level far in advance of manual systems.

5.1 TADOU: An Innovative DRT in a Rural Area

The Pays du Doubs central is a grouping of 99 communes across five little towns, located in the northeast of France. To serve the mobility requirements of the sparsely populated area of 25 000 inhabitants with 38 inhabitants per square kilometer (Castex 2007), the transport authority of the area developed a stop-to-stop DRT service named TADOU (Transport à la Demande du Doubs Central) » using the Tadvance network[8].

A set of stops cover the entire territory in a system of multidirectional flows, and passengers can travel in any direction from one stop to another after having phoned the previous day to book their trip. A software innovation named "GaleopSys" developed by Tadvance is used for DRT service, which calculates the trips booked and rationalizes them. The input data requirements of Galeopsys are stop points, timetables, and the acceptable levels of delay-time.

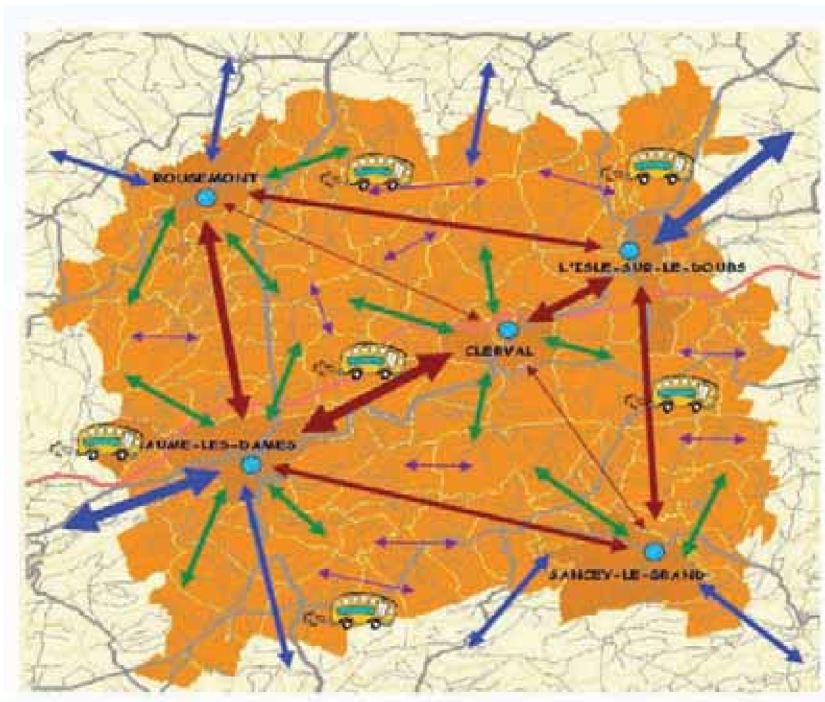
> *GaleopSys achieves trip optimization using a Geographical Information System (GIS), the database of which contains information on all the stops and passenger addresses (figure 6). The software enables the calculation of the shortest routes while maximizing the number of passengers transported by as few vehicles as possible. At the same time it ascertains that users' time constraints are respected. The algorithm developed is based on Dial A Ride Problem with Time-Windows (DARPTW) (Garaix et al., 2007); the Prorentsoft firm distributes the software.*

The cost of travel depends on the distance travelled, and is proportionally less for a longer distance of travel than for a shorter one. In 2006, the number of trips was 1863 for 2454 passengers, which corresponds to 1.3 passengers per vehicle. At the beginning of the year 2007, the service had 230 trips a month (Castex 2007).

---

[8] researchers network (Universities of Avignon and Belfort-Montbéliard) aiming at the development of DRT

FIGURE 6
Trips Optimization on GaleopSys Software (TADOU)



Source: Castex 2007.

5.2 DRT Services Complementary to Public Transport Facilities in the City of Toulouse

In 2004, a DRT service called TAD 106 (Transport à la Demande 106) was created in Toulouse by the Public Transport Authority Tisseo. The service operates as a public-private partnership with RCS Mobility[9] being the private operator subcontracting with Tisseo. The system provides people in the eastern suburban area of Toulouse with a flexible public transport service that is complementary to existing regular lines. ICT innovations used[10] for this operation focus on an information and reservation center operated by telephone and secured reservation website with a multimodal database. The database is regularly updated with software named SYNTHESE for the reservation and dispatching of trips. SYNTHESE is free software with a General Public License. Its input data requirements are the

[9] « Réseaux, Conseils et Solutions Informatiques » (RCSI)

[10] Developed by « Réseaux, Conseils & Solutions Informatiques » RCSI firm.

City of Toulouse DRT System

Features include:

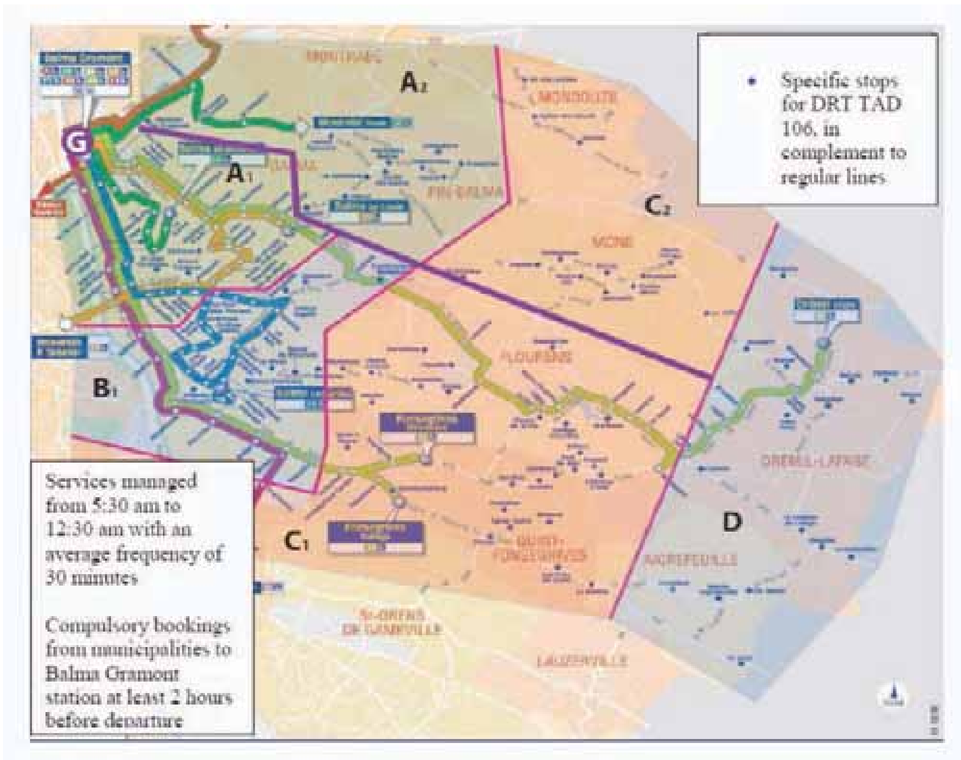
- The coverage of a large geographical scale: trips are possible on every origin/destination among 100 stop points across six municipalities;
- A direct connection to a fast and important transport mode (subway);
- High level of availability with departures every 30 minutes from 5 am to 12:30 am every day of the year;
- Flexible operations that require no pre-established itinerary, only stops and timetables are fixed;
- An adaptable system allowing for variations in the number of DRT vehicles on the roads, as a function of demand;
- A low constraint travel option for passengers since it provides the option for booking an unplanned return trip from the central area of town at the metro terminal; otherwise bookings are to be made one hour in advance with cancellations possible until the departure;
- Accessible information and booking center with special toll-free telephone lines available between 6:30am and 10:30pm everyday of the year and a secured website allowing customers to book places any time;
- The DRT service operates to complement the existing urban public transport network. There is no competition with regular lines and a common system of information is shared with them, with integrated tariff systems, etc.

stop points by zone, timetables, the window of time allowed for prior booking, and pre-existing rules of no competition with regular public transport lines. The dispatcher can consult the real-time location of DRT vehicles with the use of GPS, and can inform passengers in case of vehicle delay. As roadmap trips are transmitted automatically to the drivers from the reservation center, operating costs are optimized. There is also a permanent radio link between vehicles and the information and reservation center and the system allows the display of real-time information of DRT departures; this is available on screens at the Balma Gramont station, which is the terminal metro station. Computer terminals at the Balma Gramont station have facilities for printing the tickets for the allocated trips. The capacity of the vehicles varies from 8 to 22 passengers.

Showcasing the success of this initiative are the statistics associated with this DRT service. On average, 650 passengers/day were transported in 2009 with more than 1000 passengers/day during particular events like the Music Festival; a total of 295 000 trips were made in 2009, a 95 percent increase from 2006, with a passenger satisfaction rate of 97%[11]. Many other unique, and innovative features are associated with this DRT service are shown in Figure 7 and the box below.

[11] Data collected from DRT operator in Toulouse

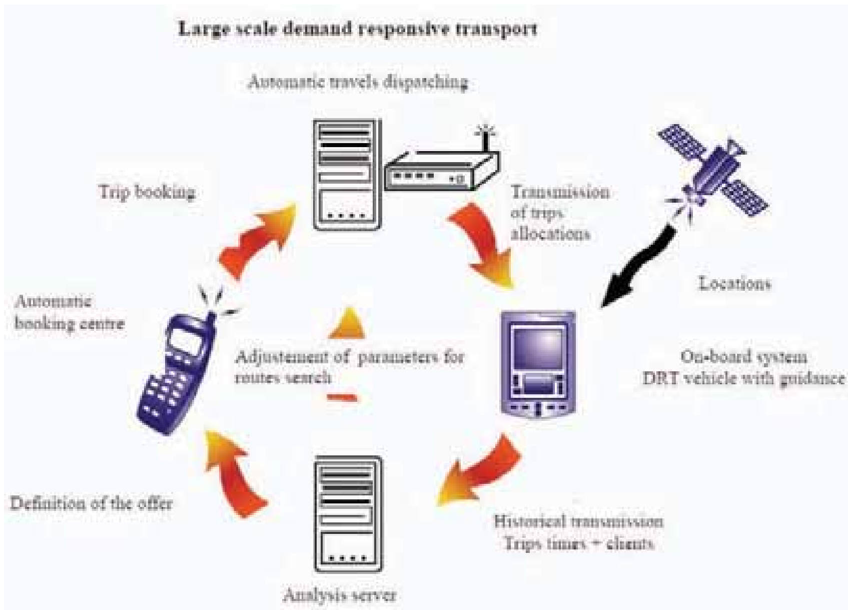
FIGURE 7
Principles of DRT « TAD 106 » in Toulouse



Source: DRT operator in Toulouse.

It is envisaged that future ICT innovations in several realms (see figure 8) will allow improvements in the quality of DRT services being offered in Toulouse and lead to the reduction of management costs. These will depend to a large extent on the will of the actors involved, including the local authority and the operators who will benefit from the integrated workings of communication satellite systems with local telecommunications networks.

FIGURE 8
Technological perspectives for DRT "TAD 106" in Toulouse



Source: DRT operator in Toulouse.

6. ENVIRONMENTAL IMPACTS OF DRT

An ADEME (French Environment and Energy Management Agency[12]) analysis (ADEME 2005) compares greenhouse gas (GHG) emissions arising from the use of urban DRT services against a theoretical situation where a passenger would use a private car for the same trip. The study concluded that:

- DRT services consume slightly more energy (10% more at the maximum), and therefore emit more GHG emissions when compared with the usage of private cars; and
- DRT operations consume much less energy than regular public transport services (at least 60% less) in areas with low mobility potential (e.g. those with low population densities).

Although the comparison shows a slightly higher level of energy consumption

[12] http://www.ademe.fr

and corresponding GHG emissions arising from the use of private cars, as opposed to DRT services for a similar trip, the results of the comparison must be interpreted with caution since many trips would not be made without the availability of DRT services. This is because one of the objectives of the DRT model is to provide mobility to those who may find it difficult to use both private and public forms of transport (e.g., elderly people, disabled, and those who do not own personal transport and/ or have inadequate access to public transport).

Apart from the above, a simulation-based assessment was also conducted on the extension (to more municipalities) of the DRT service "Evolis Gare" that provides connecting trips to the train station in the urban agglomeration of Besançon (Castex 2007). This assessment showed that a DRT service with a high rate of demand (at least three people/vehicle) enables a decrease in the number of kilometers (up to 30%) made by DRT vehicles. Therefore, if trips are optimized, DRT services can contribute to a reduction in greenhouse gases emissions arising from transportation. However, additional studies would be needed to measure these environmental impacts of DRT system services and its related ICT infrastructure.

7. CONCLUSION

One of the main reasons of the development of DRT in recent years has been the development of technology. Advances in software, computers, digital maps, remote communications, in-vehicle computers and GPS technologies have helped make DRT services viable. The examples of Doubs Central and Toulouse, two different areas, show that technology can play a key role to optimize DRT trips and bring quality service to the population in a large area, or when the patronage is high. Technology offers the potential for achieving real-time demand responsiveness in transport services, particularly in complex networks, to a level far in advance of manual systems. However, the costs of establishing high-tech schemes are significant, resulting in local authorities sometimes being reluctant to make investments in such softwares. Moreover, suppliers often provide specialized hardware rather than adapting standard platforms, which increases cost considerations and thus constrains the greater use of technology for more efficient DRT services.

There is immense potential for DRT services to develop as an economically sustainable public transport systems and alternative to the private car. In particular, DRT helps to meet the travel needs for target groups of passengers like the elderly, disabled, and other special groups. These potential markets have largely not been met by transport services because cost-effective means of meeting such demands have not been adequately developed. Operators and local authorities increasingly believe that if technical barriers can be overcome, the transport market for DRT will accelerate.

The environmental benefits of an efficiently functioning DRT system have not been adequately established yet. However, it is conceivable that if DRT system can effectively use ICT developments to achieve more flexibility in their responses to mobility requests, they can help mitigate transport related GHG emissions by limiting the use of private transport.

Glossary

ITS : Intelligent Transportation Systems

IT : Information Technology

PDA : Personal Digital Assistant

GPRS : General Packet Radio Service

GSM : Global System for Mobile communications

GPS : Global Position System

TDC : Travel Dispatch Centre

DARPTW : Dial-a-Ride Problem with Time Windows

GIS : Geographic Information Systems

References

ADEME. 2005. *Fiches Descriptives de Transport à la Demande pour Flux Faibles,* ISIS, 74.

Ambrosino, G., Nelson J.D., and M. Romnazzo. 2004. *Demand Responsive Transport Services: Towards the Flexible Mobility.* Rome: Agency ENEA.

Burkhardt, J., Hamby B., and A.T. McGavock. 1995. "Users' Manual for Assessing Service-Delivery Systems for Rural Passenger Transportation." TCRP Report 6, National Academy Press, Washington.

Bolot, J., Josselin D., and T. Thevenin. 2002. "Demand Responsive Transports in the Mobilities and Technologies Evolution: Context, Concrete Experience and Perspectives" Proc., 5th AGILE Conference, Palma, Washington.

Castex, E. 2007. *Le Transport A la Demande (TAD) en France : de l'état des lieux à l'anticipation. Modélisation des caractéristiques fonctionnelles des TAD pour développer les modes flexibles de demain,* PhD Thesis in Géography, Avignon.

Castex, E., Houzet S., and D. Josselin. 2004. "Prospective Research in the Technological and Mobile Society: New Demand Responsive Transports for New Territories to Serve" Proc., 7th AGILE Conference, Heraklion.

Certu. 2006. *Le transport à la demande, Etat de l'art, éléments d'analyse et repères pour l'action,* Dossiers du CERTU.

Datar, DTT, Ademe. 2004. *Services à la demande innovants en milieu rural: de l'inventaire à la valorisation des expériences*, ADETEC, 245.

Enoch, M., Potter S., Parkhurst G., et al. 2004. *INTERMODE: Innovations in Demand Responsive Transport.* Rapport final. Manchester.

Garaix, T., Josselin, D., Feillet, D., Artigues C., and E. Castex. 2007. « Transport à la demande en points à points en zone peu dense, proposition d'une méthode d'optimisation des tournées.» *Cybergeo*, 396: 17.

Tuomisto, J. T. and M. Tainio. 2005. "An Economic Way of Reducing Health, Environmental, and other Pressures of Urban Traffic: a Decision Analysis on Trip Aggregation." *BMC Public Health:* 14.

UTP. 2005. *Le transport à la demande dans le transport public urbain*. p. 8. *Union of Public Transport.* Paris, France.

CHAPTER 11

An Investigation of Climate Strategies in the Buildings Sector in Chinese Cities

Jun LI*

Abstract

Around 60% of Chinese people will be living in the cities by 2030 (UN 2008). Energy consumption and GHG emissions could increase exponentially with unprecedented urban expansion, and in any case with an increasingly western mode of living, in the absence of drastic policies being undertaken immediately. Due to its long lifetime characteristics, the quality of large-scale urban infrastructure is critical to the achievement of long-term and cumulative GHG emissions mitigation objectives in the next decades given the spectacular pace of urban development (e.g. China will build the equivalent of the EU's entire existing housing stock between 2005 and 2020). This research investigates the role of urban infrastructure in shaping the long-term trajectory of energy and climate securities protection and sustainable urban development prospects in China. Based on a quantitative analysis in a selected case-city (Tianjin), the research demonstrates how China's cities can embark on a sustainable energy supply and demand track by developing climate resilient building infrastructure. Also discussed are the implications for development financing policy and institutional change.

Keywords: Climate resilience, urban infrastructure, buildings, long-term trajectory, China

Corresponding author: prunush208@gmail.com

1. INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC), Conference of the Parties Fifteenth session (COP-15) in Copenhagen has set a target of 2°C by 2050, which laid the framework of the post-Kyoto global climate regime. One of the key uncertainties in the next climate negotiations is on the role that emerging countries will play in dealing with climate change mitigation and adaptation in the next two decades. A major challenge in the 21st century will be to accommodate and sustain economic growth in emerging countries while ensuring the sustainability and inclusiveness of this development (Colombier and Loup 2007). This paper seeks to outline an appropriate policy framework to enable Chinese cities to shift themselves to low-carbon development pathways by managing infrastructure quality whilst improving social welfare without hindering economic growth. China, according to the International Energy Agency, will contribute 30% of the increase in global energy demand and more than 50% of coal consumption rise by 2030 under the "business-as-usual" BAU scenario (IEA 2007a). Meanwhile, China will continue to heavily rely upon coal to power its economic development over the next few decades — due to existing infrastructure and that under construction. Due to the current and anticipated rates of construction and expansion, short-term changes will have significant consequences for long-term emissions. In other words, the trajectories that China will follow in the short-term will have extremely important implications on global energy and climate securities. This leads to a fundamental question of tackling climate change mitigation in emerging countries: Can we decarbonise a country's high-emissions sectors without hindering economic growth or causing adverse impacts on its socio-economic development?

Indeed, there exist various technological options for decoupling economic growth from increases in energy related GHG emissions from urban infrastructure: energy efficiency, renewable energy, nuclear power generation (fourth generation with minimum environmental impact), fuel switching (e.g. coal to natural gas) and carbon capture and storage (CCS). However, policy makers must take account of the availability and cost-effectiveness of these options, within the context of climate change. Most supply-side low carbon technologies (Generation IV nuclear and CCS, among others) might not be commercially available at industrial scale by 2020 or even later, as they are currently in the stage of research and pilot project demonstration. Other promising carbon-free supply technologies (e.g. Wind, Solar PV) are still confronting technical, financial and institutional barriers to be deployed at scale. In contrast, improvement in energy efficiency is the most cost-effective emission abatement measure, particularly in the buildings sector (IPCC 2007).

Buildings were responsible for nearly one-third of global CO_2 emissions in 2004[1] (IPCC 2007). However, a significant part of emission mitigation potentials in this sector remain untapped in large emerging economies like China. Due to the strong inertia and long lifetime characteristics, failure to implement energy efficiency and low-carbon technologies in buildings will increase the risk of locking cities into irreversible carbon-intensive mire for several decades. Huge social cost would also result from intensive capital investment in additional supply capacity and retrofitting infrastructure during the operation stage. Thus, the environmental quality of the newly built infrastructure will determine the level of energy consumption and of CO_2 emissions of the country for decades to come (Neuhoff et al. 2009).

2. THE CITIES IN CHINA AT THE FOREFRONT OF URBAN SUSTAINABILITY

2.1 Unprecedented Urban Growth and Increase in GHG Emissions

Cities need to be at the forefront of tackling the Climate Change mitigation challenge. Considering that half of humanity currently lives in cities, cities consume the majority (60-80%) of energy in the world and account for almost equal GHG emissions (OECD 2010); how cities develop and what they consume will determine the collective capacity to combat global warming. By 2015, 1.6 billion people will be living in cities of more than 1 million people, with 622 million in cities of more than 5 million (UNFPA 2001). Over two-thirds of the global population will live in cities by 2050 (UNFPA 2007; UN-Habitat 2008).

China, in particular, stimulated by fast economic development, will see an unprecedented scale of urban growth in the next few decades. Currently, China is adding nearly 2 billion square metres of new buildings every year. Around 20 to 22 billion square metres of buildings are expected to be constructed by 2020, equivalent to the total existing building stock area in EU-15 today (Ecofys 2006).

It is projected that 60% of Chinese population will live in cities by 2030[2]. This will drive up demand for energy services and urban infrastructure. The high CO_2 emission-urbanization elasticity in low and middle-income developing countries, found in the empirical study by Martínez-Zarzoso (2008) strongly indicates that climate change mitigation requires public policies to be put in place to decouple the CO_2 emissions from urbanization in China.

---

[1] Indirect emissions from the buildings sector through electricity use are included.

[2] Urban population projection is based on the central-C scenario of Toth et al. (2003).

Table 1
Population and Per Capita Income Growth in China During 1990-2005

Population Size		Population Growth	Per Capita Income		Per Capita Income Growth
million		%	(US $)		%
1990	2005	1990-2005	1995	2005	1990-2005
1143.3	1315.8	15.1	339	1709	404

Source: excerpted from (ASEAN 2006).

Energy demand in China has been rapidly increasing to fuel its economic growth engines and meet the growing living standard (Table 1). As a result of the high-rate economic development and urbanization, primary energy demand increased four-fold during 1980-2005. In 2005, China consumed 1560 million tons of oil equivalent (Mtoe) energy and energy-related CO_2 emissions were 5100 Mt, representing 57% of Asia's total[3] (IEA 2006; BP 2008).

Past experiences in developed countries show that during the early stage of economic take-off, residential demand for energy services increases rapidly before reaching a sufficiently high level, comparable to current high-income countries. A recent study (Azomahou et al. 2006) using statistical analysis showed that the per capita CO_2 emission in China is following an upward trend with respect to economic development[4]. This "virtuous circle" of improved quality of urban infrastructure and standard of living creates fundamental issues of meeting the growing demand while minimizing the energy and environmental implications. The world would struggle in terms of energy resources availability and climate governance if the past tendency in the United States and Europe were reproduced in China.

The rapid urbanization and changing perceptions of comfort among building occupants implies that China will develop all the means to meet the fast-growing demand for energy services, driven by economic development and a more westernized lifestyle. Demand for energy services is positively correlated with household income. It is projected that per capita income in China could increase to US$10,000 (PPP) by 2020 (NDRC 2004a), implying significant increases in household demand for various energy services. Meanwhile, the ageing population trend implies significant adjustment of the urban household structure, i.e., the number of households will increase while household size will be smaller. Empirical studies show that the energy demand per capita is much

[3] Japan is included in the calculation.

[4] Statistically significant at 5% level, countries like India and China are pursuing the upward trend of per capita CO_2 emission as per capita GDP increases (Azomahou et al. 2006).

higher for small households than in large households[5]. Furthermore, it is anticipated that low-income and rural residents will gradually switch to energy sources such as natural gas or electricity derived from coal, from conventional biomass energy (mostly crop straw and stalk), which is still widely used in rural areas for cooking and heating.

2.2 Climate Resilient Buildings to Avoid the Long Term Lock-In

Large-scale urban infrastructure, such as buildings, has a long lifetime. Inappropriate decision on investment in infrastructure quality could result in irreversible energy and emissions lock-in. By comparison, retrofitting existing buildings and those soon to be constructed is comparatively very costly and requires short-, medium- and long-term action. At present the investment decision is mainly oriented by short-term objectives of meeting the mass market's demand and maximising the profits of developers without necessarily accounting for the long-term consequences of climate change mitigation and adaptation. The governance and relevant institutional capacity of many local authorities is fairly weak in dealing with the quality management of urban infrastructure, leading to questions of how to enhance governance of urban development through reorienting sectoral investment choice towards low-carbon technologies and planning strategies at the local level. Buildings will certainly play an overarching role in the (Low Carbon Economy) LCE transition process in a city due to its long supply and value chain.

3. CHANGING PATHWAY OF BEE IMPROVEMENT IN CHINESE CITIES

3.1 Modelling Framework and Key Assumption

This section discusses how to make appropriate investment decisions in energy performance improvement in the buildings sector in China based on a bottom-up modelling approach. The quantitative analysis is based on a case study in the city of Tianjin using the Long Range Energy Alternative Planning; or LEAP model (Heaps 2008), a bottom-up energy technology simulation model. Modelling includes final and primary energy demand, environmental impacts in terms of carbon emissions, as well as the total costs

[5]For example, the US (1997) residential survey shows that the average per capita energy consumption in a 5-person household and 3-person household is 25 and 37 Mbtu respectively, while the per household member consumption is 75 Mbtu in the single-member household.

in each scenario. The primary objective is to investigate the economic and environmental performance of Building Energy Efficiency (BEE) improvement portfolios in order to identify the portfolio in which the present value (PV) of total costs is minimised. We compare five central scenarios, namely TJ-2004 (business as usual), RT-2005 (equivalent to the French efficiency standard in 2005), SWE (equivalent to the Swedish standards), LC (with more stringent BEE targets in new buildings), and ParCom (delay in BEE implementation in new building constructions). The technical calculation of thermal and appliance consumption in the residential and commercial sectors for buildings constructed in compliance with different BEE standards is detailed in Li (2009).

In Chinese cities, per capita floor area is expected to approach 30 square meters by 2020 according to the national housing development program (MOC) and a previous study by Zhou et al. (2007). It is assumed that this will rise to approximately 35 square meters per capita in 2030, also considering that the average house size will increase more slowly after 2020. Coupled with the household size in 2030, average housing floor space will then be around 96.5 square meters, roughly equivalent to the current level in Japan and the average of the EU-15 in 2004[6].

Household thermal comfort is projected to progress accordingly to keep pace with increasing living standards. It is assumed that comfort levels for the inhabitants in Tianjin and those in developed countries will converge eventually. With indoor temperature approaching the international benchmark of residential comfort level, it is assumed in the model that heating temperature will pursue a continuous upward trend to approximate 22°C by 2030. Combining the factors of increases in heating temperature and heating period length will give the underlying energy demand indicator, the heating degree day (HDD).

Renewables (urban and rural wastes), co-firing, CHP, fuel switching (GS; from coal to natural gas) and Carbon Capture and Storage (CCS) are considered in the alternative energy supply options in which new technologies are assumed to be deployable from 2020 in the model. Estimate of costs associated with thermal efficiency improvement, household electric appliance ownership, and supply technologies is based on Liu (2006), Zhou et al. (2007) and Li et al. (2009); cost of CCS is based on Rubin et al. (2007).

---

[6]Housing size ranges between 75 and 110 square metres, the average is about 91 square metres in EU-15 in 2004 (Bosseboeuf 2007).

3.2 Component of Costs

The boundary of cost defines the scope of economic analysis. The model considers the following costs in the calculation boundary within the modeling period:

- energy performance enhancement cost, including efficient building materials, envelope insulation, ventilation, metering, regulation systems, etc.;
- energy resources cost — coal, natural gas, oil, biomass, etc. - using a proxy of fuel price, capital cost of heat and electricity (average and marginal investment in increasing new generating capacity to meet the growing demand);
- fixed operation and maintenance (O&M) cost;
- variable O&M cost; and
- cost of environmental externalities (CO_2 emissions).

3.3 Costs and Implications for Climate Policy

3.3.1 Annual Cost in the Scenarios

The annual cost in each of simulated scenarios is presented in Table 2. This demonstrates that the BEE enhancement in the case of RT-2005 and SWE will be systematically less costly than the reference case. While LC is more difficult to implement, the cost will fall below that of the reference case in the long-term. However, the upfront cost during the first decade of the modelling period will be significantly higher than that of the reference case. This suggests that a more intelligent financial arrangement will be needed to reallocate the limited economic resources in order to achieve the cost-effectiveness target. In contrast, failure in implementing BEE in new construction in the next decades will generate very significant cost consequences in the case of ParCom. One striking result is that ParCom will never be cheaper than efficiency compliance scenarios.

TABLE 2
Annual Cost in the Simulated Scenarios (in million CNY)

	2010	2015	2020	2025	2030
ParCom	14660	22800	28380	32060	34300
TJ-2004	13595	19862	24232	27007	28938
RT 2005	13535	19051	22686	24870	26387
A2	13595	19634	23299	25284	26244
SWE	13777	18479	21387	22981	24110
LC	17008	20226	21692	22425	22492

Source: Author's calculation

The situation will be worsened if the city decides to opt for low-carbon supply systems (CCS or geologic storage) from 2020 under carbon emission constraints. The costs associated with these backstop technologies will soar in the less efficient cases (see Tables 3 and 4). A sharp jump of annual cost is predicted in 2020 when CCS will begin to be deployed in part of coal-fired power plants. However, the cost of SWE+CCS is almost identical to the reference cost, and more importantly, the cost of LC with CCS option in 2030 will still lie below the level of the reference case. By contrast, the reference+CCS and ParCom+CCS scenarios will lead to a 14% and 30% jump in annual costs, respectively, compared with the reference line. This is totally unacceptable for the local authority because huge financial resources would be required to cover the significant increase in operation cost of introducing the CCS. This implies that efficient buildings scenarios have more flexibility in facilitating the technological transition in energy supply, contrary to the sharp increase in costs in the starting year of new technology penetration in the less efficient scenarios. It can also be seen that the difference between scenarios in 2030 would deepen compared with the situation in 2020 when new

TABLE 3
Annual Cost with Introduction of CCS Option from 2020 on (in million CNY)

Scenario	2010	2015	2020	2025	2030
REF	13595	19862	24232	27007	28938
REF+CCS	13595	19862	27692	35966	39086
RT05+CCS	13460	19390	25926	33473	36108
SWE+CCS	13610	18800	24182	30243	31942
LC+CCS	15050	19950	23262	27439	27494
ParCom+CCS	14870	23350	31436	39087	42038

TABLE 4
Annual Cost with Introduction of Fuel-Switching Option from 2020 on (in million CNY)

Scenario	2010	2015	2020	2025	2030
REF	13595	19862	24232	27007	28938
REF+GS	13521	20526	27532	36715	42672
RT05+GS	13460	19390	25050	32660	37550
SWE+GS	13647	18884	23679	30020	33811
LC+GS	15123	20172	23144	27631	29044
ParCom+GS	14907	23466	31369	40735	47280

Source: Author's calculation

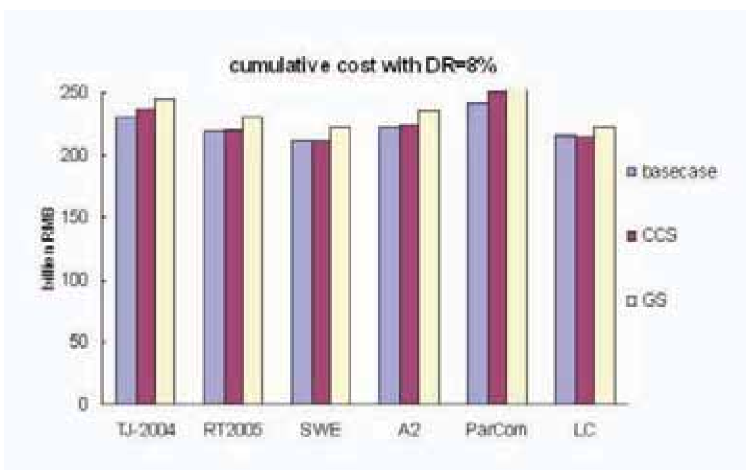
technology penetration begins. In the long run, efficient buildings can help achieve the investment strategy which allows smooth sectoral transformation toward gradual decarbonization of the city's coal-fired supply system without significant impact on financial resources reallocation.

3.3.2 Total Accumulated Cost Under Carbon Constraints

One fundamental point of economic analysis is that the determinant of BEE investment will be related to the present value of the series of yearly costs. How the cost will be redistributed is another issue. Figure 1 presents the accumulated costs with different energy supply technologies under moderate-level carbon constraints by assuming a carbon price of \$50/t CO_2 in 2030.

The discounted rate used in the calculation is 8%, consistent with risk in large-scale fixed capital investment return and the indicative long-term housing mortgage rate. SWE allows for the lowest discounted costs in all scenarios, implying that the current BEE target needs to be tightened further by 50% to address both energy and climate concerns for the long-term investment decision.

FIGURE 1
Discounted Cumulative Cost



Source: Li 2009.

3.3.3 Imperative of Changing Pathway

Table 5 compares the cost of carbon emission abatement in different scenarios of BEE standards and energy supply systems. It is clearly shown that the city needs to tighten the BEE requirements immediately in the scenario of unconstrained coal-based energy supply as the mitigation costs are almost negative except for the LC scenario. However, it could be predictable that Chinese cities will shift gradually from the current coal-based supply technologies in the longer term; consequently, we also draw the comparison of costs in the cases of penetration of CCS and fuel-switching from coal to gas under the carbon constraints from 2020 on. Likewise, the more stringent buildings performance are even more necessary if the city is to decarbonise its energy supply infrastructure through scaled deployment of CCS and fuel switching (GS); the second and third columns of Table 5 show that the costs would increase substantially in the scenarios of lower energy efficiency in buildings. The strategy matrix highlighted in bold refers to the best choices in which the costs of abatement will be significantly lower than otherwise. This means that city must commit itself to embarking on the energy performance and supply pathways shown in the bottom-right of Table 5. However, the trade-off between CCS and GS will not be clearly arbitrated until 2020 when the cost and availability will reveal the feasibility of each option. Engaging in one sole supply option to reduce carbon emissions is likely to increase the risk that either the technology or energy supply will be unavailable. A portfolio decision turns out to be more relevant and risk-averse from an investment decision standpoint.

TABLE 5
Comparison of Abatement Costs (US $/tCO$_2$ in 2005 price)

	Coal BAU	CCS	GS
RT2005	-56	32	39
A2	-38	43	67
SWE	-43	**7**	**8**
LC	1	**11**	**14**

Note: Reference is TJ-2004 coupled with coal-fired heating system. *Source:* Li (2009).

3.4 Implications for Climate Policy

The modelling results clearly demonstrated that the current building efficiency standard practiced in Chinese cities is not an optimal choice because the discounted cumulative cost could be reduced further by upgrading BEE standards. The analysis of annual costs shows that, despite a remarkable incremental investment costs in all enhanced BEE scenarios, the increase in required investment is considerably less in the high efficiency case (LC) than in the lower efficiency case (ParCom). To avoid a sharp jump in current year operation costs, such as in the ParCom scenario, upfront buildings energy performance and quality of construction are of critical importance, otherwise the city will be trapped in a vicious circle: lower efficiency buildings resulting in costly operation and thus decreased financial capacity to invest in low-carbon technologies to mitigate carbon emissions in the future.

Further, if the actions are conceived to be credited by demonstrating additionality, the robustness of a baseline definition, metrics (policy based, intensity-bases or fixed target) and MRV issues of emissions, accountability, environmental effectiveness, and economic efficiency all will need to be taken into account. Unilateral, bilateral or multilateral actions in infrastructure quality improvement require establishment of relevant institutions and evaluation bodies as well as recognised procedures.

4. CONCLUDING REMARKS

China will have strong political and economic interests in enhancing energy efficiency in the large-scale urban infrastructure to transform the nation's populous cities into low-carbon infrastructure facilitators. It is demonstrated that inaction would result in tremendous irreversible costs compared to proactive approaches aiming to significantly improve the quality of urban infrastructure in Chinese cities. The modelling results presented here corroborate the findings of the Stern Report (2007).

A multi-dimension and trans-sectoral policy framework needs to be established to ensure the implementation of low carbon infrastructure development policies. A comprehensive market for energy-efficient technologies and products needs to be created. Domestic models can be tested based on the development of clean technologies and their diffusion, and sharing experience with developed countries in the establishment of policies aimed at the following: regional planning; integrated urban planning; the implementation of energy performance standards for buildings and amenities; soft practices and support programmes aimed at local authorities and stakeholders in the building and transport sectors.

In conclusion, a sustainable future in urban infrastructure in Chinese cities requires changing the pathway of sectoral development and involves profound institutional and governance transformation in the whole process of urban development policy making. Integrated approaches should be adopted by Chinese policy makers with regards to building energy efficiency and sustainable transport. The sooner that China moves towards a low-carbon infrastructure, the better placed the world will be in terms of minimising the climate change-related risks.

References

ASEAN Secretariat. 2006. *Asean, China and India: Comparative Economic Performance, Issues and Implications.*

Auffhammer, M., and Carson R. 2008. *Journal of Environmental Economics and Management* 55 (3): 229–47.

Azomahou,T., and Laisney Van P. 2006. "Economic Development and CO_2 emissions: A Nonparametric Panel Approach." *Journal of Public Economics* 90 (6–7): 1347–63.

Bosseboeuf, D. ed. 2007. *Evaluation of Energy Efficiency in the EU-15: Indicators and Measures.* Ademe, France.

BP Statistical Review of World Energy 2008 Database. B.P.

Centre for Housing Industrialization, Ministry of Construction. 2007. http://www.chinahouse.gov.cn/cyfz16/160002.htm.

Chinese Ministry of Construction. GB 50189-2005. *National Public Building Energy Saving Design Standard* (Effective since January 1, 2006).

Colombier, M., and Loup J. 2007. "Reorienting our Societies: Climate Change Analyses" In *Energy and Climate Change: the Main Analyses of regard sur la Terre*. IDDRI.

Cosbey, A., Ellis J., Malik M., and Mann, H. 2008. *Clean Energy Investment Project Synthesis Report*. IISD.

Department of Energy (DOE), Washington. US. EIA. International Energy Outlook. (2006). DOE, Washington. Energy Issues, 24 (3/4).

Ecofys. 2006. *Mitigation of CO_2 –Emissions from the Building Stock*.

Greening, L., Greene D., and Difiglio C. 2000. "Energy Efficiency and Consumption — the Rebound Effect — A Survey." *Energy Policy* 28 (6–7): 389–401

http://www.cin.gov.cn/INDUS/speech/2003111801.htm

Hu,C., Chen L., Zhand C., Qi Y., and Yin, R. 2006. "Emission Mitigation of CO_2 in Steel Industry: Current Status and Future Scenarios." *Journal of Iron and Steel Research,* 2006 13 (6): 38–42, 52.

IEA (International Energy Agency). 2004. *Energy Statistics Database 2004*. www.IEA.org.

______. 2006. *World Energy Outlook*. International Energy Agency. Paris.

______. 2007a. *World Energy Outlook 2007 China and India Insights*. International Energy Agency. Paris.

______. 2007b. "Scaling up Energy Efficiency: Bridging the Action Gap." Workshop Background Paper. April 2–3 2007.

IPCC (Intergovernmental Panel on Climate Change). 2007. "Mitigation." Contribution of Working Group III to the Fourth Assessment Report of the IPCC, ed. B. Metz, O..R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer, 60. United Kingdom: Cambridge University Press; New York.

Li, J. 2008. "Towards a Low-Carbon Future in China's Building Sector—A Review of Energy and Climate Models Forecast." *Energy Policy* 36 (5): 1736–47.

______. 2009. Policy Instruments for Buildings Energy Efficiency in China, *Ecole des Mines de Paris.* Ph.D Thesis Dissertation, *unpublished*.

Li, J., Colombier M., and Giraud P.N. 2009. "Decision on Optimal Building Energy Efficiency Standard in China—The Case for Tianjin." *Energy Policy* 37 (7): 2546–59.

Ministry of Construction of China. 2003.

NBS (National Bureau of Statistics). 2004. *China Statistical Yearbook 2004*. Beijing.

NDRC. 2004. *China's Energy Development Strategies and Policy Implications (Scenario Analysis on Energy Demand*. Beijing.

Neuoff, K., Fankauser S. Guerin E., Hourcade J., Jackson H., Rajan R., and Ward J. 2009. "Structuring International Financial Support to Support Domestic Climate Change Mitigation in Developing Countries." Climate Strategies ISDA Working Paper.

OECD (2010), *Cities and Climate Change*, OECD Publishing.

Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. 2005. *World Population Prospects: The 2004 Revision*. CD-ROM. New York: United Nations. http://www.un.org/esa/population/publications/WPP2004/wpp2004.htm.

Rubin, E., Chen C., and Rao A. 2007. "Cost and Performance of Fossil Fuel Power Plants with CO_2 Capture and Storage." *Energy Policy* 35 (2007): 4444–54.

Stern, N. 2007. *Stern Review on the Economics of Climate Change*. London: HM Treasury.

Toth, F., Cao G., and Hizsnyik E. 2003. *Regional Population Projection for China*. Austria: IIASA.

UNEP (United Nations Environment Programme). 2008. *A Reformed CDM-Including New Mechanisms For Sustainable Development.* Riso Centre.

UNFPA (United Nations Population Fund). 2001. The State of World Population 2001.

______. 2007. The State of World Population 2007.

UN-HABITAT (United Nations Human Settlement Programme). 2008. *Urban World*.

World Bank. 2001. *China : Opportunities to Improve Energy efficiency in Buildings*. Washington, DC: World Bank.

Zhou,N., McNeil M.A., Fridley D., Lin J., Price L., De la Rue du Can S., Sathaye J., and Levine M. 2007. *Energy Use in China: Sectoral Trends and Future Outlook,* 96. Lawrence Berkeley National Laboratory.

CHAPTER 12

Opportunities and Challenges to Electrical Energy Conservation and CO_2 Emissions Reduction in Nigeria's Building Sector

John-Felix Akinbami,* Akinloye Lawal

Summary

Using an energy demand model, MADE — II (Model for Analysis of Demand for Energy), the electrical energy demand for the household, commercial, and industrial buildings, on a long-term period was estimated for Nigeria based on the concept of useful energy demand. This analytical tool uses a combination of statistical, econometric, and engineering process techniques in arriving at the useful electrical energy demand projections. The associated CO_2 emissions were also estimated. These projections reveal that the electrical energy growth is enormous especially considering the associated financial cost, and the estimated CO_2 emissions are also substantial. This study therefore discusses the potentials for efficient energy use in the buildings sector in Nigeria. In addition, obstacles to the full realization of energy-saving potentials in the nation's building sector are discussed. Finally, a framework of strategies to overcome these obstacles, promote energy conservation, and thereby enhance sustainable development in the nation's built environment is suggested.

*Corresponding author: akinbami_jfk@yahoo.com

1. INTRODUCTION

Energy literally fuels the economy of a country. Without energy, economic development would not be possible, human survival would be threatened and national security would be jeopardized. Energy is therefore an inextricable part of a nation's security. While sustainable energy policies seek to provide us with the energy needed at the least financial, environmental and social cost, energy efficiency encourages policies or practices which help us to evaluate the full cost of our energy choices and to get more output from a unit of energy. Sustainable energy planning should be done on the basis of cost-effectiveness, continuous availability, unrestricted supply, and satisfactory regard for the environment. Energy efficiency encompasses conserving a scarce resource, improving the technical efficiency of energy conversion, generation, transmission and end-use devices, substituting more expensive fuels with cheaper ones, and reducing or reversing the negative impact of energy production and consumption activities on the environment.

In the face of increasing demand for energy and especially electricity in all sectors, more efficient use of energy has to be considered as one of the major options to achieve sustainable development both in Nigeria and even globally in the 21st Century. Buildings in the tropical areas of the world are constantly exposed to solar radiation almost on a daily basis. Building design should aim to minimize heat gain indoors and maximize evaporative cooling, so that users of these spaces can have adequate thermal comfort, and reduce dependence on air conditioning and electricity use. The demands for electricity in a building are primarily for space cooling and heating, refrigeration, lighting, motive power (motors), and heating (process and cooking). Energy in buildings can be classified into two types: energy for the maintenance/servicing of a building during its useful life; and energy capital that goes into production of a building (embodied energy) using various building materials (Venkatarama and Jagadish 2003). For a complete understanding of building energy needs, a study of both types of energy consumption is required.

This paper deals with the energy needs of buildings during their service lives, and presents an energy demand model (MADE-II — Model for Analysis of Demand for Energy) which is used to project the long-term demand for electrical energy from households and from commercial and industrial buildings in Nigeria. The model is based on the concept of useful energy demand, and uses a combination of statistical, econometric and engineering process techniques to project future energy demand as well as associated CO_2 emissions. Based on the model results, this paper then discusses the potential for efficient energy use in the buildings sector in Nigeria, as well as the obstacles to the full realization of this potential. In the final section, a set of strategies are suggested to overcome these obstacles, promote energy conservation, and enhance sustainable development in Nigeria.

1.1 Global Trends in Energy Consumption and Associated CO_2 Emissions in the Building Sector

The key drivers of energy use and related greenhouse gas (GHG) emissions in buildings include activity (population growth, size of labor force, urbanization, number of households' per capita living area, and persons per residence), economic variables (change in GDP and personal income), energy efficiency trends, and carbon intensity trends. These factors are in turn driven by changes in consumer preferences, energy and technology costs, settlement patterns, technical change, and overall economic conditions. Urbanization, especially in developing countries, is clearly associated with increased energy use, as commercial fuels, especially electricity, become easier to obtain. As countries modernize, the expected level of comfort (i.e. floor area per person, amount of air conditioning, lighting level, electric appliances, etc.) also increases, often causing energy (especially electricity) consumption in buildings to increase more rapidly than in other sectors (Levine et al. 1991).

Buildings constitute a significant and rapidly growing energy consuming sector. Between 1971 and 1995, world primary energy use in the buildings sector grew from 61.5 — 109.8 exajoules (EJ). While residential building sector energy use grew from 41.7 to 69.4 EJ, that of the commercial sector more than doubled from 19.8 to 40.3 EJ (IPCC 2001) (see Table 1). There has been an observed steady decrease in the average annual growth rate (AAGR) in the same period. Correspondingly, the associated carbon dioxide (CO_2) emissions grew from 1,140 to 1,732 million tons of carbon (MtC) for the global buildings sector between 1971 and 1995 (Table 2). On a disaggregated basis, that of the residential building sector grew from 775 to 1,148 MtC while that of commercial buildings grew from 364-584 MtC in the same period. Table 2 further reveals that the corresponding CO_2 emissions in the aggregate buildings sector in Africa grew from 15 to 48 MtC in the same period. Of this, CO_2 emissions from residential buildings grew from 11 to 39 MtC, while that of the commercial sector grew from 3 to 9 MtC in the same period (IPCC 2001). Table 1 also shows that in Africa, there was a steady increase in primary energy use in both residential and commericla buildings, and consequently in the total primary energy use of buildings. According to the International Energy Agency (1989), buildings in the developing countries, account for 28% of total commercial energy use and 38% of electricity use.

TABLE 1
World Primary Energy Use by Sector and Region in the Buildings Sector 1971-1995 (Exajoule) (EJ)

Building sector	Primary energy use (EJ)						Average annual growth rate (%)		
	1971	1975	1980	1985	1990	1995	1971-1990	1990-1995	1971-1995
Developed Countries	44.4	48.9	52.3	56.8	62.3	68.5	1.8	1.9	1.8
Residential	28.3	30.5	33.0	34.6	36.7	40.6	1.4	2.0	1.5
Commercial	16.1	18.4	19.3	22.2	25.6	27.9	2.5	1.7	2.3
Economies in Transition	10.7	13.0	18.2	21.0	23.0	16.2	4.1	6.8	1.7
Residential	8.1	9.8	12.9	14.3	15.1	10.4	3.3	7.2	1.1
Commercial	2.6	3.2	5.3	6.7	7.9	5.8	6.0	6.1	3.4
Asia Pacific	3.6	4.6	5.6	7.9	10.2	12.9	5.7	4.8	5.5
Residential	3.0	3.9	4.6	6.3	7.9	9.3	5.2	3.4	4.8
Commercial	0.0	0.8	1.0	1.6	2.3	3.6	7.8	9.0	8.1
Africa	0.6	0.8	1.1	1.4	1.9	2.5	6.0	5.4	5.9
Residential	0.5	0.6	0.8	1.1	1.5	2.0	6.1	6.0	6.0
Commercial	0.1	0.2	0.3	0.3	0.4	0.5	5.8	3.1	5.2
Latin America	1.7	2.1	2.8	3.3	4.1	5.0	4.9	4.1	4.7
Residential	1.3	1.6	2.0	2.3	2.9	3.4	4.2	3.3	4.0
Commercial	0.3	0.5	0.8	0.9	1.2	1.6	7.0	5.8	6.8
Middle East	0.4	0.7	1.2	2.2	4.1	4.6	12.3	2.8	10.3
Residential	0.4	0.7	1.1	2.0	3.4	3.7	11.5	1.8	9.4
Commercial	0.0	0.0	0.1	0.2	0.7	1.0	20.2	7.0	17.3
Rest of World	2.7	3.7	5.1	6.9	10.1	12.1	7.1	3.8	6.4
Residential	2.2	2.8	3.9	5.4	7.8	9.1	6.8	3.2	6.0
Commercial	0.5	0.8	1.2	1.5	2.3	3.0	8.5	5.7	7.9
World	61..5	70.3	81.3	92.6	105.6	109.8	2.9	0.8	2.4
Residential	41.7	47.1	54.5	60.6	67.4	69.4	2.6	0.6	2.2
Commercial	19.8	23.2	26.8	31.9	38.2	40.3	3.5	1.1	3.0

Source: IPCC 2001.

TABLE 2
World Carbon Dioxide Emission by Sector and Region in Buildings Sector 1971-1995 (Million tonnes of carbon) (MtC)

Building sector	Carbon dioxide emission (MtC)						Average annual growth rate (%)		
	1971	1975	1980	1985	1990	1995	1971-1990	1990-1995	1971-1995
Developed Countries	790	836	886	887	915	958	0.8	0.9	0.8
Residential	522	543	549	537	539	560	0.2	0.8	0.3
Commercial	268	293	336	350	377	398	1.8	1.1	1.7
Economics in Transition	240	296	362	381	373	320	2.3	3.0	1.2
Residential	164	213	266	290	279	256	2.9	1.8	1.9
Commercial	76	83	97	92	94	64	1.1	7.3	0.7
Asia Pacific	67	88	131	179	232	292	6.7	4.7	6.3
Residential	57	75	110	145	180	210	6.2	3.1	5.6
Commercial	10	14	21	33	51	81	9.0	9.7	9.1
Africa	15	18	23	30	38	48	5.0	5.1	5.0
Residential	11	12	16	22	29	39	5.1	6.0	5.2
Commercial	3	6	7	8	8	9	4.8	1.7	4.2
Latin America	18	21	24	24	30	34	2.6	2.8	2.7
Residential	14	16	19	19	22	24	2.5	1.6	2.3
Commercial	4	5	6	5	8	10	3.2	5.9	3.7
Middle East	9	13	23	41	58	80	10.5	6.7	9.7
Residential	7	10	17	30	41	59	10.0	7.6	9.5
Commercial	2	4	6	12	17	21	12.0	4.3	10.3
Rest of World	42	52	71	95	125	162	6.0	5.3	5.8
Residential	32	38	52	70	92	122	5.7	5.8	5.7
Commercial	10	14	19	25	33	40	6.7	4.0	6.2
World	1140	1273	1450	1542	1646	1732	2.0	1.0	1.8
Residential	775	869	977	1042	1091	1148	1.8	1.0	1.6
Commercial	364	404	473	500	555	584	2.2	1.0	2.0

Source: IPCC 2001.

Global projections of primary energy use for the buildings sector show a doubling, from 103 to 208 EJ, between 1990 and 2020 in a baseline scenario (IPCC 2001). The most rapid growth is expected in the commercial buildings sector, which is projected to grow at an average rate of 2.6% per year. Under a scenario where state-of-the-art technology is adopted, global primary energy consumption in the buildings sector could grow to about 170 EJ in 2020. A more aggressive "ecologically driven/advanced technology" scenario, which assumes an international commitment to energy efficiency as well as rapid technological progress and widespread application of policies and programs to speed the adoption of energy-efficient technologies in all major regions of the world, could result in primary energy use of 140 EJ in 2020.

The current low efficiency of energy use in buildings in developing countries presents a significant opportunity for energy conservation. Energy conservation calls for a collective endeavor, in that it stems from the actions of people in diverse fields, although the people involved may not be sufficiently informed or motivated to conserve energy. In many developing countries including Nigeria, the system-wide peak electricity demand occurs in the early evening, coinciding with the peak use in buildings (especially homes). Thus, energy conservation in the buildings sector will significantly reduce the load during peak hours when electricity is most expensive to generate, and will mitigate the problem of load shedding that often occurs during peak hours because demand exceeds supply. The next section presents information on Nigeria's building sector.

2 TRENDS IN ENERGY CONSUMPTION AND ASSOCIATED CO_2 EMISSIONS IN NIGERIA'S BUILDING SECTOR

2.1 Past Trends

In this section, the discussion will focus only on electricity consumption in residential, commercial and industrial sectors of the Nigerian economy. Included under the commercial sector are public buildings, community buildings, hotels, hospitals, etc. Table 3 shows that in 1990, total electricity consumption in the country was 28.22 Petajoules (PJ), which amounted to 3,949 GWh. Of this, 14.22 PJ (50.39%) went to the residential sector; 6.67 PJ (23.64%) went to the commercial sector while the remaining 7.33 PJ (25.97%) was consumed in the industrial sector (Federal Office of Statistics 1995). In 1995, while the total national electricity consumption was 35.24 PJ, 17.77 PJ (50.43%) of this was consumed in the residential sector, 9.94 PJ (28.21%) was consumed in the commercial sector and the remaining 7.53 PJ (21.37%) went to the industrial sector (Federal Office of Statistics 1998).

TABLE 3
Past Electricity Consumption Trend in the Residential, Commercial and Industrial Sectors

Year	Residential Sector (PJ)	Commercial Sector (PJ)	Industrial Sector (PJ)	Total Consumption (PJ)
1970	1.60	0.87	1.65	4.13
1975	3.68	2.15	3.95	9.77
1980	7.67	2.77	5.91	16.35
1985	11.47	2.70	7.96	22.13
1990	14.22	6.67	7.33	28.22
1995	17.77	9.94	7.53	35.24
2000	15.04	7.54	6.54	29.12

Source: FOS (Federal Office of Statistics) 1995; 1998; 2000.

In 2000, total electricity consumption amounted to 29.12 PJ. The residential sector accounted for 51.65% (15.04 PJ) of this, while the commercial and industrial sectors accounted for 25.89% (7.54 PJ) and 22.46% (6.54 PJ) respectively of the total national consumption (Federal Office of Statistics 2000). It must be noted that the observed reduction in total electricity consumption between 1995 and 2000 was not as a result of energy conservation measures and technologies; rather, it is likely attributed to suppressed demand of electricity due to unreliable and inadequate national grid electricity supply in the country.

2.2 Future Trends

2.2.1 Methodology

For the estimation of future trends of electricity demand, an energy demand model, Model for Analysis of Demand for Energy (MADE-II) was employed. This study has employed the concept of useful energy demand (that is, actual energy use for energy services such as cooking heat, lighting, process heat, motive power, etc.). This allows for the analysis of inter-fuel substitution possibilities and estimation of the optimal supply. In analyzing energy demand for a developing country like Nigeria, certain socio-economic parameters have to be considered. These parameters include rural-urban dichotomy, income distribution inequalities, non-commercial energy dominance (such as fuelwood and charcoal), and rapid structural transformation in the economy. The model incorporates the above-mentioned basic socio-economic parameters of the Nigerian energy system in the analysis of the future energy demand.

Three methodologies were used for carrying out energy demand analysis: statistical, econometric, and engineering process techniques. This model — MADE-II (Saboohi 1989) — was chosen and adapted for the Nigerian situation partly because it uses a combination of statistical, econometric, and engineering process techniques in arriving at the useful energy demand projections, and partly because of its flexibility. The statistical technique aspect is used to extrapolate the trends of energy demand into the future. The econometric technique uses an estimated function relating energy demand with fuel prices and income. The engineering process technique represents the core methodology of MADE-II. It is a simulation technique that uses socio-economic development and technical changes as the most important determinants of energy demand. The model represents all technical processes in the energy sector with great detail.

Another striking feature of MADE-II is its flexibility, which makes it adaptable for the various problems normally encountered in energy demand analysis. For example, one can go into any level of disaggregation in the analysis, depending on the data available and the objective of the demand analysis. Technical changes such as improvement of efficiencies and reduction of energy intensities through scientific progress and technical innovations play a significant role in the demand. These aspects are included in the demand analysis by using technical efficiencies for various end-use technologies and appliances in order to obtain the useful energy demand for all sectors.

MADE-II was developed so that energy demand could be considered in relation to socio-economic development. The projection of useful energy demand is based on the information about population growth and socio-economic development. In MADE-II, demographic data, that is, population growth and share of rural and urban areas are considered as exogenous parameters. The basic analytical approach in MADE-II involves the calculation of the base year energy intensity (energy per unit of service in every sector of an economy, for example, quantity of energy used to produce one ton of steel in the manufacturing or industrial sector) for the various end-use categories for different sectors of the economy. This is derived by relating the total energy consumption for that end-use service by the measure of activity level of that service. Future energy intensities are then derived based on simulation concepts. Once the future year energy intensity is obtained, useful energy requirements are calculated by multiplying future projected activity level with the energy intensity. In this demand model, useful energy requirement, UE for end-use category j, for group g, of economic sector s, in time period t, is given as:

$$\mathbf{UE}_{j,g,s,t} = \mathbf{AL}_{j,g,s,t} * \mathbf{EI}_{j,g,s,t} \quad (1)$$

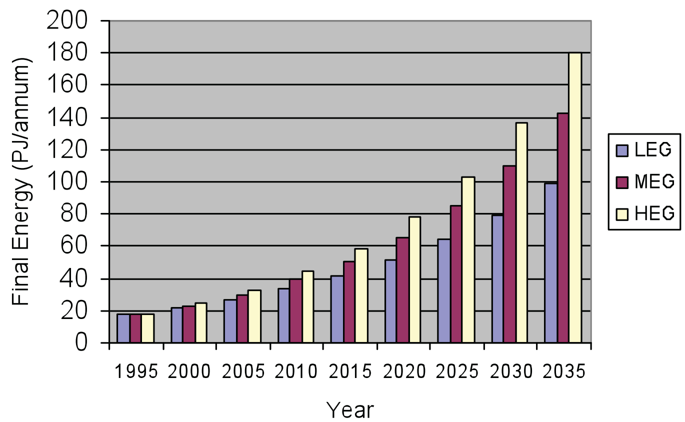
where $\mathbf{AL}_{j,g,s,t}$ is the activity level for end-use category j of group g of economic sector s in time period t, and $\mathbf{EI}_{j,g,s,t}$ is the energy intensity for end-use category j, for group g, of economic sector s, in time period t.

Due to the uncertain evolution of developing country economies which the Nigerian economy typifies, three energy demand scenarios which represent three different patterns of energy development were adopted for the energy demand projections. These are the LEG scenario which represents low economic growth and hence low energy growth; the MEG scenario assumes moderate economic growth and development and hence, a moderate energy growth; and HEG, the high energy growth scenario, which represents strong economic and social growth. The projection spans through 25 years with 1995 as the base year. It is expected that Nigeria's actual energy growth pattern will most probably be between the LEG and HEG scenarios.

2.2.2 Analysis of Results

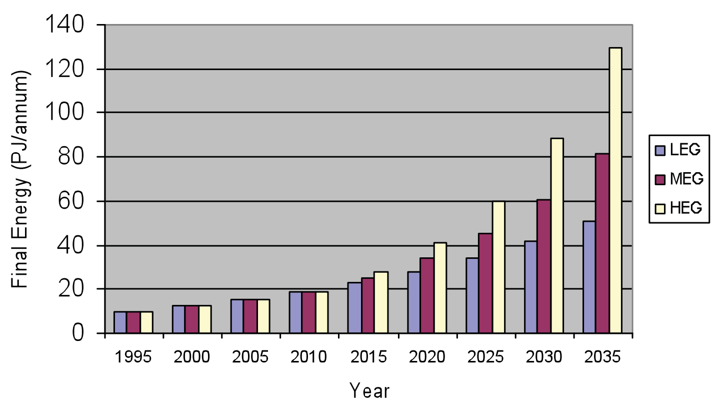
An analysis of the results of the model reveals that under a moderate energy growth (MEG) scenario, the final energy demand for electricity has been estimated to grow from 17.78 to 65.43 PJ between the period 1995 and 2020 in the residential sector. In the industrial sector, the growth is expected to be from 9.55 to 33.85 PJ and from 8.02 to 21.60 PJ in the commercial sector within the same period (Figures 1, 2 and 3). Sectorally, electricity consumption in the household sector would increase 11.1%, 17.1% and 22.3% per annum in the LEG, MEG and HEG scenarios respectively. Similarly, in the industrial sector, it is expected to grow at the rate 10.5%, 18.3% and 30.7% for the three scenarios LEG, MEG and HEG respectively while for the commercial sector, the growth rate will be 7.3%, 13.3% and 22.6% respectively. On aggregate, total electricity consumption growth rates in the LEG, MEG and HEG scenarios are expected to be 10.1%, 16.6% and 24.6% respectively. Whichever energy growth path is taken, the growth is potentially enormous, especially considering the associated finance. Figure 4 gives the CO_2 emissions trend from Nigeria's electricity supply system for the period 1995-2035 (Akinbami 2003). The observed decrease in emissions may be due to the choice of the linear optimization model, used for the energy supply analysis in the country, to use electricity supply technologies which are less CO_2 or non-CO_2 emitting towards the end of the study period.

FIGURE 1
Final Energy Demand Projections for Electricity in Three Energy Scenarios for Residential Sector in Nigeria



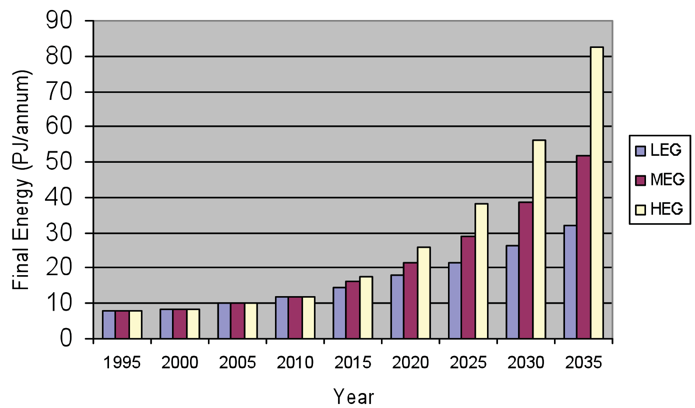
Source: Akinbami 2003.

FIGURE 2
Final Energy Demand Projections for Electricity in Three Energy Scenarios for Industrial Sector in Nigeria



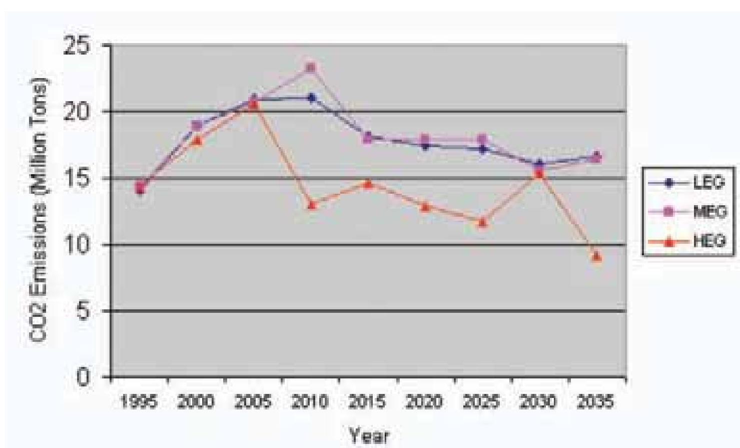
Source: Akinbami 2003.

FIGURE 3
Final Energy Demand Projections for Electricity in Three Energy Scenarios for Commercial Sector in Nigeria



Source: Akinbami 2003.

FIGURE 4
CO_2 Emissions Trend in Nigeria's Electricity Sector



Source: Akinbami 2003.

3 EXISTING BUILDING DESIGN PRACTICES — HOW ENERGY EFFICIENT?

Buildings in the tropical areas of the world are constantly exposed to solar radiation. Hence, building design should aim at minimizing heat gain indoors and maximizing evaporative cooling, so that users of these spaces can have adequate thermal comfort and consequently make less demand of active energy. These buildings should therefore be bioclimatically responsive; in other words, having shapes and forms which:

- Are properly oriented;
- Have a building fabric specified to prevent or minimize heat gain; and
- Respond to passive energy and have minimal use of active energy for economic viability.

For building design purposes, overheated regions of the world, which generally refer to the tropical areas, are classified into three categories: (1) hot/warm and arid/semi arid regions, (2) warm and humid regions, and (3) temperate, both arid and humid regions (Bowen 1975; Ajibola 2001). Based on this classification, Nigeria is in the warm-humid region. In this region, there are two distinct seasons, the dry season, which is from November to March, and the rainy season from April to October. Other observations include that climate varies as one moves from the coast to the northern parts of the country, and with the time of the year, latitude of the location and landscape (Ideriah and Suleman 1989).

Observations of most buildings in Nigeria (both traditional and contemporary) reveal that most of the above-mentioned criteria have not been strictly adhered to. It has been further observed that traditional buildings in Nigeria have laid too much emphasis on socio-cultural and economic factors (Costa 1989). In addition, contemporary buildings have depended on imported building materials. Various problems have emanated from even the present design approaches and philosophy (Ajibola 1997; Ajibola 2001). Some of these are:

- Most buildings seem to be replicas of buildings in European countries in shape and form despite marked differences in climatic conditions;
- Despite observed climatic differences in various cities within the country, forms and shapes of buildings tend to look alike;
- Windows of buildings have not been properly oriented to maximize air movement for space cooling indoors;
- Window sizes and openings have not responded to physiological comfort

thereby necessitating the use of mechanical devices for increased air movement. The choice of windows tends to be in response more to aesthetic needs rather than physiological needs;

- Material specification for buildings in the housing sector have followed the same pattern despite the difference in climate within the country;
- The desire for more usable space makes the provision of single windows in spaces unavoidable especially in hotels and other commercial buildings; and
- Due to the limitations of the land and other considerations, the idea of getting all spaces in a building cross-ventilated is not feasible.

The existing building designs in the country have promoted inefficient energy use. This has translated over the years to increasing demand for active energy through the various devices for both lighting and adequate indoor thermal comfort. Unless intervention measures are put in place to contain this trend, the situation will remain the same and even exacerbated with time.

Ajibola (2001) has observed that the climate of Nigeria cannot be regarded as strictly homogeneously warm-humid even though it lies within the latitude 5^{o}-16^{o} N. Most cities have composite climates. Due to paucity of climate data and lack of energy conscious building designs, these pertinent issues are not taken into consideration. However, for a comfortable indoor environment, which is energy conscious, to be achieved, the microclimate of the locality in which the design is taking place should be considered. The analysis of climate data closely related to the design environment will lead to more adequate and precise design decisions in terms of:

- Adequate orientation;
- Spatial organization;
- Prevention of heat gain into spaces; and
- Better choice of building materials.

A climatic classification useful for architectural building design must have a combined effect of temperature, relative humidity, mean radiation temperature, and wind velocity.

4. OPPORTUNITIES FOR ENERGY CONSERVATION IN BUILDINGS

If the building envelope and building materials were adequately considered to allow for a longer time period for daylighting, and maximum indoor space cooling, this would reduce the time needed for electrical energy for both lighting and cooling devices. Consequently, this will promote energy conservation. Apart from the building envelope, opportunities also exist for energy conservation in the lighting and cooling devices sub-sectors. For instance, due to the high first-cost of fluorescent bulbs, incandescent bulbs are still the predominant electric lighting device in the country. Hence, approximately 34.3% of total electricity use in urban households goes to lighting (Adegbulugbe and Akinbami 1995).

The tropical climate of Nigeria definitely makes space cooling an essential energy service. This is provided by electric fans and air conditioners. Fans have a much higher market share than air conditioners in Nigerian households because of their lower investment costs and lower electricity consumption. A study (ibid.) has revealed that electricity consumption by fan cooling ranges between 2% and 8% while the total average consumption is 7% of the total household electricity consumption in the various household income groups in the country. Similarly, the percentage share of electricity consumption by air conditioners to the total household electricity consumption ranges between 0% and 2% with a total average of 1.5%. Resulting from the downturn in economy in the past two decades, the Nigerian market has become a dumping ground for second-hand products from abroad. Due to overuse before shipment, the efficiencies of these products would have dropped already. These consequently add to energy inefficiency in Nigerian buildings (ibid.).

If energy efficient lighting devices such as the compact fluorescent lamps (CFL) as well as energy efficient cooling devices, such as fans and air conditioners, were promoted in the country, these would help in reducing both electric lighting and cooling energy. Putting all these energy savings opportunities in the residential buildings alone together, it is estimated that at least 10% of total residential electrical energy use will be conserved. Based on the results from energy audits conducted in the country for two refineries, two cement plants, one steel plant and a furniture manufacturing plant which indicate that about 25% of energy used in these industries can be saved through good housekeeping measures (Adegbulugbe 1991), it is assumed that about 10% of both total industrial and commercial sectors' electricity demand could be saved. Ultimately, these would lead to a reduction in greenhouse gases emissions in the country.

5. BARRIERS TO ENERGY CONSERVATION IN BUILDINGS

Several factors act as obstacles to the full realization of energy-saving potentials in the nation's buildings sector. Some of them are:

5.1 Lack of Awareness

The lack of or limited awareness of the potential of energy efficiency is likely the most important obstacle to wide-scale adoption of energy efficiency measures and technologies in the country (Adegbulugbe 1991) generally, and particularly in the buildings sector. This is a by-product of two major issues. One is inadequate information infrastructure to raise the level of awareness of the potential of energy efficiency (including costs and benefits) as well as the available technologies and proven practices. The other issue is a lack of an overall energy demand management policy. If there were an energy demand management policy, this would probably have necessitated the need to develop a databank on the proven measures and technologies that promote rational energy utilization which would be available to the public for effective implementation of the policy .

5.2 Energy Supply Constraints/Lack of Incentives and Motivation

Even when there is a desire to adopt energy efficiency measures, the structure of the electric energy supply may be a bottleneck. Due to an unreliable supply of electricity in Nigeria, the motivation to adopt any conservation measure or technology is limited. In addition, a general lack of incentives, such as tax rebate or low customs and excise duties on imports of improved energy efficient technologies, hinders both the importers and consumers.

5.3 Inappropriate Energy Pricing

Pricing is an important tool to promote efficient use of energy. However, the energy pricing regime in Nigeria is still perceived to be below the marginal opportunity cost (MOC), a result of the government monopoly of the electricity sector and the use of energy supply solely as a social service (provision of energy far below production cost through government subsidies) in order to achieve political objectives. Successive governments have upheld the culture of energy subsidies in the country. Over the years, this has sent the wrong signals to energy consumers to the extent that any attempt to raise energy prices to the MOC level has often led to both social and political upheavals. In addition, the energy subsidy culture has discouraged any incentive for innovation on energy efficiency measures.

5.4 Private and Public Buildings

Often, houses are built, especially by the affluent, with a view to projecting prestige rather than from the economic perspective. Such buildings are generally devoid of energy efficiency features. Lack of information on trends in energy efficient architecture among professionals is a formidable obstacle. This has also encouraged a lack of energy-conscious building standards and regulations. Furthermore, the investor/user or landlord/tenant dilemma also helps to discourage energy efficiency. For instance, if the user or tenant is allowed to make energy saving investments, he stands the risk of not enjoying the pay off for the whole life cycle of the investment if his tenancy or contract is terminated abruptly, and the investor or landlord may not give any refund on the investment already made. For public buildings owned by various government authorities (local government, state and federal or national authority), the budgeting format is usually "annual budgeting fixation", which means that they cannot transfer funds from the 'recurrent' budget to the 'capital' budget. With a lot of other and probably more urgent pressing needs calling for capital investment, energy efficiency measures are given the lowest priority. The poor perception of public goods also adds to the obstacles confronting energy efficiency in the country. For instance, electricity bills for government buildings are rarely paid; hence there is no urge to adopt even simple housekeeping measures to conserve electricity.

5.5 Lack of skilled Manpower and Technical Know-How

There is a limited and inadequate human resource capacity to carry out energy audit studies and projects in general, and to design energy efficient buildings in particular, in Nigeria. Energy engineers are rather few in the country. Coupled with this is the fact that few professionals in the building sector have training on energy-efficient building designs. These may have been borne out of a sense of non-need for such skilled manpower due to a long persistent culture of inappropriate energy pricing in the country. However, the era of low energy pricing is gradually fading away. Provision of the required skilled manpower entails specialized training which most Nigerian tertiary institutions are not providing presently. Consequently, it is necessary to review the educational curricula in tertiary institutions to close this gap. There is a general dearth of skilled manpower and adequate technical know-how on how to carry out technical energy conservation measures in the country.

5.6 Lack of legislation

A lack of legislation may imply non-availability of standards, or where such standards exist, non-compliance may result from lack of enforcement. These issues expose the Nigerian Energy Market (NEM), and hence the consumers, to sub-standard technologies which are likely to be energy inefficient and may have even been outlawed in their country of manufacture. Both non-availability of standards and lack of enforcement of standards, where they exist, discourage local manufacturers of energy technologies from investing in improving the efficiency of their products.

6. POSSIBLE STRATEGIES TO PROMOTE ENERGY CONSERVATION IN THE BUILDING SECTOR

6.1 Development of Adequate Database

Energy efficiency improvement programs aim to reduce unnecessary energy costs through identification and elimination of inefficiencies. This requires the collection and proper analysis of relevant data, which can help to indicate whether or not there is need for improvement in energy use. For the data acquisition activity, the building sector should be compartmentalized into various sub-sectors in which the electricity use can be adequately monitored and analyzed. Such sub-sectors may include the building envelope, which could be further compartmentalized into lighting system, cooling system, building materials, etc. The databank should also include other energy conscious building parameters and energy efficient devices and measures.

6.2 Research, Development, Demonstration and Dissemination (R,D,D&D)

Funding of research is needed in tertiary institutions and appropriate research institutes in order to develop building designs that allow for a longer period of use of passive energy than obtained presently. The research activity should also be extended to building materials for physiological comfort, ceiling and roofing materials that will prevent or minimize heat gains in the different parts of the country. Of course the R,D,D&D should also include external designs that provide sufficient shade, reduce solar radiation reflections into the building and thereby reduce demand for active energy services in the building. These may include shade trees, green facades, etc.

6.3 Awareness Campaign/Outreach Program

As the old adage says, "knowledge is power". There is the need for the electric utility, federal ministries and agencies involved in energy and housing matters and the building private sector to reach out to the public, including: investors, professionals, planners, and decision makers through various campaign programs such as seminars, conferences, workshops, radio/television talks and programs. The campaign should be taken to the grassroots in order to educate every stakeholder in the buildings sector on the needs for, benefits of, and options for energy conservation in the sector.

6.4 Legislative and Regulatory Support

Measures to promote energy conservation in the country need adequate legislative and regulatory backing. This will involve the institutionalization of standards and codes, as well as incentives and motivation that will enhance the national promotion of energy conservation. For the buildings sector, various professionals and all other stakeholders will have to be involved in the legislative and regulatory processes for meaningful and functional legislative measures and regulatory practices.

7. CONCLUSIONS

The model results from the MEG scenario, which may likely be Nigeria's energy growth and development pattern in the future, reveal that electrical energy consumption in both the residential and industrial sectors will increase more than three-fold, while that of the commercial sector will increase about three-fold over 25 years in the period 1995-2020. The financial resources required to put in place the supply infrastructure to meet this demand are quite substantial. The observed high growth pattern of the electricity demand also shows the high potential for energy conservation measures. Putting all the energy saving opportunities already discussed in place, it is estimated that at least 10% of total residential electrical energy use can be conserved while it is also assumed that about 10% of both total industrial and commercial sectors electricity demand could be saved. These would ultimately lead to a reduction in green house gases emissions in the country.

Hence, for sustainable economic growth and development, energy conservation should be a preferred energy supply option in Nigeria, to enhance energy security, reduce wastage in the energy system, delay construction of new energy supply infrastructures, conserve financial resources for other development programmes, and reduce environrmental and climatic problems. However, for serious and beneficial energy conservation in the buildings sector, the government needs to take some necessary steps in addition to those already suggested. These include:

- Leadership by example — just as practical steps were taken in the US to conserve energy in the White House, similar steps need to be taken by the Federal Government with respect to all the federal public buildings – Aso Rock Villa (the Presidential Office and Villa}, the National Assembly Complex (the Legislature), Federal Secretariat and other Federal Government buildings including the armed forces buildings, etc. The government should be seen as the vanguard of energy conservation;
- National building codes, standards, regulations should be developed jointly by the various professional bodies, other stakeholders and government. As mentioned earlier, the building codes and standards should be based on research of the local climatic conditions;
- In order to further promote energy conservation, incentives for the production, marketing and utilization of energy efficiency goods and services; and technologies should be implemented;
- Buildings should be rated according to their energy efficiency indices in order to make them attractive for rental and investment;
- Building that incorporate renewable energy applications for use as thermal energy and electricity generation should be encouraged with incentives during the design and post-construction stages;
- Energy impact assessment for new buildings should be made compulsory nationwide as is being suggested to be practiced now in Lagos State;
- To enable buyers to make robust and well-informed decisions, it is necessary that all appliances imported into the country be tested to conform to national standards labeling, and that all electrical equipment be adequately labeled;
- Research and development, demonstration and dissemination in design and materials for energy conscious architecture should be well funded by both government and the private sector;
- More awareness campaigns need to be mounted by both government and private sector for continuous education of the populace which consist of would be investors, professionals, planners, law and decision makers on both the macroeconomic and microeconomic benefits of energy conscious buildings;
- Development of energy conscious building parametrics and energy efficient devices and measures databank;

- Educational curricula of architecture, building and allied departments in the tertiary institutions may have to be reviewed to incorporate issues that relate to contemporary energy conscious architecture and building designs and materials in order to raise and increase the skilled manpower required in this area; and
- International cooperation with countries of similar climatic conditions to Nigeria for information and data exchange and research collaboration needs to be promoted.

Acknowledgements

The Authors gratefully acknowledge the comments and suggestions of Lara Opperman of Construction Economics and Management, University of Cape Town, South Africa in an earlier version of the paper at the Technology and Management for Sustainable Building Conference, South Africa.

References

Adegbulugbe, A.O. 1991. "The Energy-Environment Nexus: The Role of Energy Efficiency." Paper presented at the Conference on "Energy Issues in Nigeria: Today and Tomorrow," Nigerian Institute of International Affairs, Victoria Island, Lagos, Nigeria.

Adegbulugbe, A. O., and Akinbami J-F.K. 1995. "Urban Household Energy Use Patterns in Nigeria." *Natural Resources Forum*, 19 (2): 125–33.

Ajibola, K. 1997. "Ventilation of Spaces in a Warm, Humid Climate — Case Study of Some Housing Units." *Renewable Energy* 10 (1): 61–70.

______. 2001. ''Design for Comfort in Nigeria — A Bioclimatic Approach." *Renewable Energy* 23 (2): 57–76.

Akinbami, J-F.K. 2003. An Analysis of the Demand and Supply of Electricity and the Greenhouse Gases Emissions of the Nigerian Electrical Power Industry. A Ph.D. Thesis, *Technology Planning and Development Unit (TPDU)*, Obafemi Awolowo University, Ile-Ife, Nigeria.

Bowen, A. 1975. "Some Historical Indicators for Building Design under Natural Conditions in Overheated Region." Paper presented at the Annual Conference of the Afro-Asian Housing Organization, N.B.O. New Delhi, India: Nirva Bharan.

Costa, R. 1989. "Architecture in Black Africa: Between Development and Tradition." *Solar Wind Energy* 6 (4): 383–87.

FOS (Federal Office of Statistics). 1995, 1998, 2000. *Annual Abstract of Statistics*. Nigeria.

Ideriah, F.J.K., and Suleman S.O. 1989. "Sky Conditions of Ibadan during 1975-1980." *Solar Energy* 43 (6): 325–30.

IPCC (Intergovernmental Panel on Climate Change). 2001. *Technological and Economic Potentials of Greenhouse Gas Emissions Reduction in Climate Change 2001 – Mitigation.* Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, ed. Bert Metz, Ogunlade Davidson, Rob Stewart, and Jiahua Pan.

IEA (International Energy Agency). 1989. *World Energy Statistics and Balances, 1971-1987*. Paris.

Levine, M.D., Gadgil A., Meyers S., Sathaye J., Stafunk J., and Wilbanks T. 1991. "Energy Efficiency, Developing Nations, and Eastern Europe." A Report to the U.S. Working Group on Global Energy Efficiency, USA.

Saboohi, Y. 1989. *Model for Analysis of Demand for Energy (MADE-II), IKE 8-19*. University of Stuttgart, Stuttgart, Germany, ISSN 0173–6892.

Venkatarama Reddy, B.V., and Jagadish K.S. 2003. "Embodied Energy of Common and Alternative Building Materials and Technologies." *Energy and Buildings* 35: 129–37.

CHAPTER 13

A New Water Paradigm for Urban Areas to Mitigate the Urban Heat Island Effect

Marco Schmidt

Summary

Evaporation of water is the largest and most important hydrological component on earth. Only water that has evaporated will cause rainfall, and the effects of deforestation and growing urbanization are causing significant losses to global evapotranspiration. Reduced evapotranspiration, locally and globally, means more short-wave global solar radiation is converted to long-wave thermal emissions and sensible heat. Thus, reduced evaporation causes higher surface temperatures and is a main contributor of the urban heat island effect. Rainwater harvesting measures can play a key role in further mitigation strategies against increased surface temperatures and drought. This new approach changes the focus of rainwater management to evaporation, rather than infiltration or discharge into sewers. Several demonstration projects have been established in Berlin that give insight into a new water paradigm for rainwater management in urban areas.

Key Words: Evaporation, evapotranspiration, climate change, rainwater harvesting, evaporative cooling, urban heat island effect, green roofs, green facades, new water paradigm

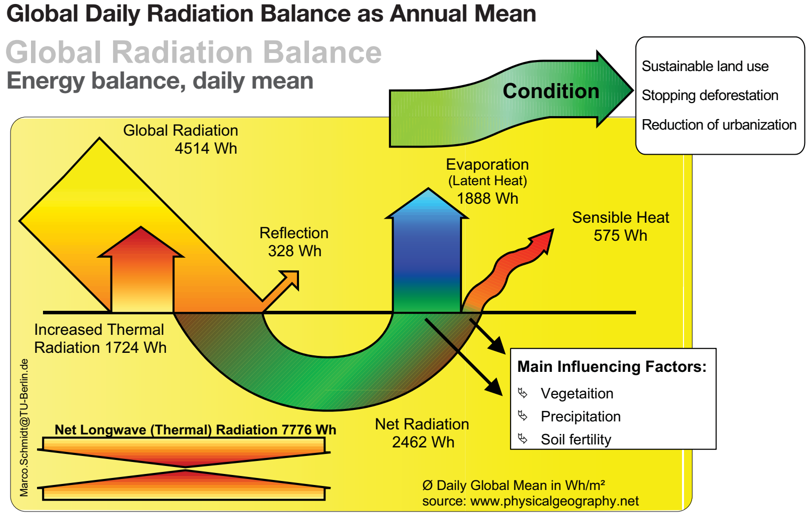
*Corresponding author: marco.schmidt@tu-berlin.de

1 INTRODUCTION

Evaporation of water is the largest hydrologic process on earth and the most important component of energy conversion. Figure 1 illustrates the components of global radiation conversion on the Earth's surface, for a mean energy flux of one square meter per day. Of this, 7.3% of incoming solar radiation is reflected and 38% is directly converted to thermal radiation due to the increase of surface temperatures. The total long-wave (thermal) radiation consists of atmospheric counter-radiation (7776 Wh/ (m^2d)) and the thermal radiation of the surface of the Earth (7776 + 1724 Wh/ (m^2d)). Compared to other available figures about the global mean energy budget (e.g. Kiehl & Trenberth, 1997; Trenberth et al., 2009), both components are presented separately in Figure 1. All surfaces above –273°C emit long-wave radiation, as they receive at the same time. Therefore, the long-wave energy gain and loss of the atmosphere, the atmospheric counter-radiation, must be considered separately from conversion of short-wave global radiation to thermal radiation.

Net radiation can be either converted into sensible heat (575 Wh/ (m^2d)) or consumed by evaporation, a conversion into latent heat. With 1888 Wh/ (m^2d), the energy conversion by evaporation is the largest component of all, even more than the thermal radiation converted from incoming short-wave radiation. Additionally, evaporation reduces the long-wave thermal radiation due to the decrease in surface temperatures.

FIGURE 1
Global Daily Radiation Balance as Annual Mean



Source: Schmidt, 2009. Energy data based on www.physicalgeography.net

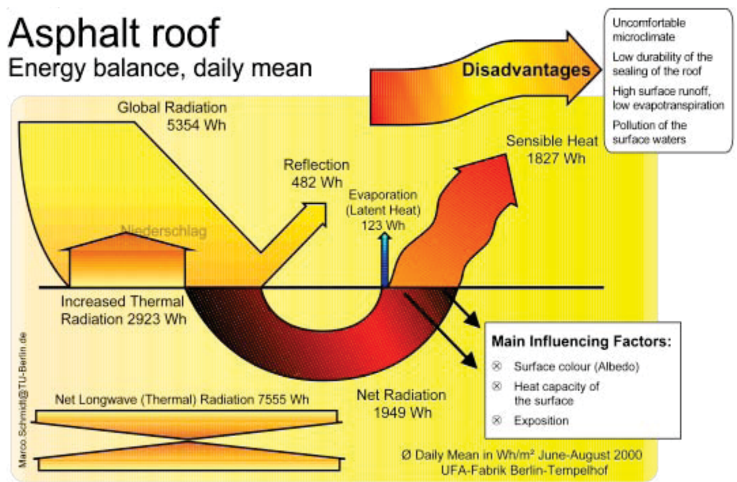
With consideration of Figure 1, the entire global radiation balance is dominated by evaporation and condensation. Just as rainfall volume depends on the amount of water that has evaporated, so will a reduction in evaporation mean the increased conversion of short-wave global solar radiation to long-wave emissions and sensible heat. Additionally, a reduction in evaporation on land translates to a reduction in overall precipitation, effecting a further reduction in evapotranspiration, thus creating a chain reaction.

Evaporation rates are being reduced in direct correlation with worldwide deforestation, sprawling urbanization, and the loss of fertile agricultural land (GTZ 2007; Kravčík et al. 2007). In Germany, for example, urbanization continues to grow at a rate of more than 1 km² daily (UBA 2008). As a result of this urbanization, an annual reduction of 200 mm evaporation releases sensible heat and thermal radiation of 50,000 GWh ($0.2\ m^3/a * 680\ kWh * 1\ Mio\ m^2 * 365\ d$). Moreover, the associated loss of vegetation further impacts hydrological processes, causing extreme storms, floods, drought, and desertification (Kravčík et al. 2007).

FIGURES 2 AND 3
An Urbanized Landscape (Rio De Janeiro, left) in Contrast to Natural Landscapes (Germany, right) Significantly Alter a Region's Patterns of Radiation and Hydrology

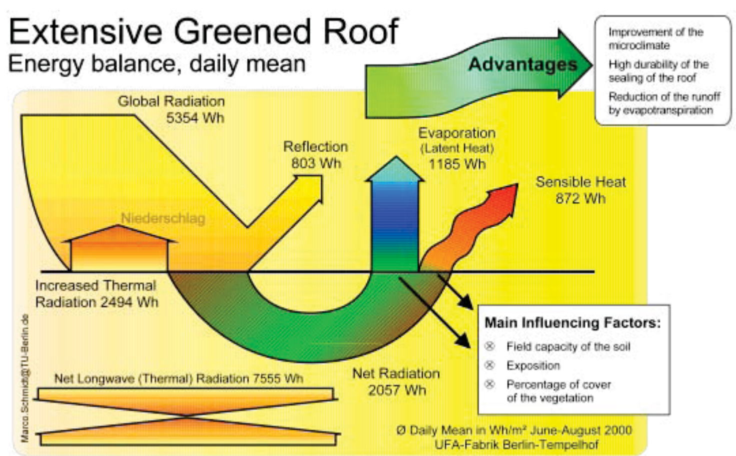

A reduction in evapotranspiration leads to the conversion of short-wave global solar radiation into long-wave thermal emissions and sensible heat. Reduced evaporation rates cause higher surface temperatures and contribute greatly to the urban heat island effect. Additionally, hard materials and surfaces in urban areas absorb and re-radiate solar irradiation and increase that area's heat capacity. As an example of radiation changes in urban areas, Figure 4 illustrates the radiation balance of a black asphalt roof. Compared to Figure 1, most of the net radiation from the urban setting is converted to sensible heat rather than evaporation. Higher surface temperatures also increase the thermal radiation.

FIGURE 4
Radiation Balance of a Black Asphalt Roof as an Example for Urban Radiation Changes



Source: Schmidt, 2005.

FIGURE 5
Extensive Green Roofs Transfer 58% of Net Radiation into Evapotranspiration During the Summer Months, UFA Fabrik in Berlin, Germany



Source: Schmidt, 2005.

As a result of changes in radiation, air temperatures inside buildings also rise. This leads to discomfort or excessive energy consumption for air-conditioning. Greening buildings is a logical solution to create more comfortable air temperatures in cities and to improve the microclimate around buildings. "Green" in this sense means to green façades and roofs, thereby "consuming" this energy by evapotranspiration. According to measurements taken at the UFA Fabrik in Berlin, a greened vegetated roof covered with 8 cm of soil transfers 58% of net incident radiation into evapotranspiration during the summer months (Figure 5). The annual average energy conversion of net radiation into evaporation is 81%, the resultant cooling-rates are 302 kWh/ (m^2*a) with a net radiation of 372 kWh/ (m^2*a) (Schmidt 2005). The roof in Figure 5 was monitored parallel in the direct neighborhood to the asphalt roof in Figure 4 for the same period.

2. BEST PRACTICE PROJECTS

With regard to the urban heat island effect and global warming, sustainable architecture and landscaping need to consider the natural water cycle, including evaporation, condensation and precipitation. Rainwater harvesting measures could play a key role in mitigating the urban heat island effect. This approach would mean that rainwater management must focus on evaporation rather than discharge into sewer systems or infiltration. Table 1 shows priorities and measures for sustainable urban development.

Water quality and other environmental issues are also considered.

TABLE 1
Priority List of Sustainable Measures for Urban Areas Regarding the Mitigation of the Urban Heat Island Effect and Global Warming

Priority	Value		Measure
1.	+ + +	3.0	unpaved greened areas (parks, greened courtyards, street trees)
2.	+ + O	2.3	green building developments (green roofs, green facades)
3.	+ +	2.0	artificial urban lakes and open waters
4.	+ OO	1.7	rainwater harvesting (for cooling and irrigation)
5.	+ O	1.3	trough infiltration combined with large vegetated structures, grass pavers
6.	+	1.0	rainwater harvesting for toilet flushing and further utilisation
7.	OO	0.7	trough infiltration systems through natural soil, semi-permeable surfaces
8.	O	0.3	trench infiltration directly into the underground

The conventional principle of water discharge, which was implemented for over a hundred years, nowadays bears disastrous environmental effects on surface water quality and on the climate. The paradigm shift, which must now be implemented on the local level, will require a complete rethinking of the existing urban planning and water management.

In Germany, rainwater infiltration has been a popular strategy in recent years. However, in spite of the great benefit of preventing negative impacts to surface waters, infiltration does not fully reflect the natural water cycle. The missing hydrological component in urban areas is evaporation rather than infiltration (SenStadt 2007). In the catchment area of Berlin/ Brandenburg in Germany, about 80% of precipitation is converted to evaporation, while groundwater recharge and runoff together represent 20%. Urban areas are characterized by completely paved areas as well as semi-permeable surfaces with little to no vegetation. The semi-permeable surfaces allow much higher groundwater recharge compared to naturally vegetated areas (Schmidt et al. 2005, SenStadt 2007), as they over-compensate for infiltration with reference to completely paved surfaces. Therefore, in the interest of effective environmental priority, the provision for evaporation rather than infiltration needs to become a primary task.

Natural groundwater recharge in the region Berlin/ Brandenburg represents 10-20% of annual precipitation. Artificial infiltration systems manage an additional 6-10 times the surface of the infiltration area itself. This represents 500% - 900% of natural precipitation as runoff from paved areas, or about 40-50 times more than natural conditions. For example, a park area in Berlin receives 600 mm of precipitation annually. A grassy area without any artificial irrigation would typically evaporate about 500 mm into the atmosphere, while 100 mm serves for groundwater recharge, mainly in the winter season. An infiltration system in the neighborhood receives the same 600 mm of annual precipitation, plus an additional 4500 mm surface runoff from paved areas adjacent. Following the rates above, these 5100 mm of water would be converted into about 700 mm evaporation, while 4400 mm represent groundwater recharge. This level of recharge is 44 times higher than the natural water cycle would permit (see Figure 6) (compare SenStadt 2007).

FIGURE 6
Trough Infiltration System in Berlin, Lacking Vegetation (priority 7)

However, infiltration can also lead to evaporation provided that vegetation and vegetated structures are constructed in the neighborhood. In such a case, infiltration systems must be supplemented with trees or façade greening systems. A discussion about the overcompensation of groundwater recharge by infiltration systems should not neglect the benefit of preventing rainwater from being discharged into sewers and surface waters. Nonetheless, we must expound the impacts on the natural water cycle and on groundwater quality in urban areas. For this reason, rainwater harvesting for toilet flushing gets a higher ranking in Table 1 compared to infiltration systems.

With a focus on rainwater harvesting and evaporation, four projects have been established in Berlin in cooperation with the "Watergy" working group (Chair of Building Technology and Design) and the Chair of Applied Hydrology. All projects combine different measures of Table 1 to increase the efficiency of the water related environmental benefits.

2.1 DCI Berlin, Potsdamer Platz

The **DaimlerChrysler-Project at Potsdamer Platz in Berlin** (from 1996-1998 the largest construction site in Europe) was built under very strict stormwater management regulations. In order to avoid overloading the existing combined sewerage system in central Berlin, the building permit issued by city council stated that the new complex would drain runoff at a rate of no more than 3 l/ sec/ ha, or 1% of flows during storm events. To comply with this regulation, the Atelier Dreiseitl (www.dreiseitl.de) and landscape architect Daniel Roehr implemented the following techniques for the management of 23,000 m^3 precipitation that falls annually on this building site:

- extensive and intensive green roofs on all of the 19 buildings
- collection of roof-runoff for toilet flushing and plant irrigation
- an artificial lake for rainwater retention and evaporation

FIGURE 7
Urban Lake, Supplied with Roof-Runoff at Potsdamer Platz (priority 3)

Since infiltration was not possible at this site, the basis for the rainwater management concept involved rainwater harvesting for toilet flushing and evaporation by green roofs and an urban lake as a retention pond. Three cisterns providing 2,550

FIGURES 8 AND 9
Greened Roofs, UFA-Fabrik Berlin-Tempelhof (priority 2)

m^3 storage capacity correspond directly to 12% of the annual precipitation of the catchment area. The artificial lake, covering a total area of 13,000 m^2, can fluctuate its levels by 30 cm, which corresponds to an additional storage capacity of 11% of the annual precipitation. The water is cleaned and filtered through artificial filtering systems and, additionally, by a constructed wetland of 1,900 m^2, which is planted mainly with Phragmites. The resulting water quality, as well as stormwater issues, have proven that this large rainwater system have performed very well for the last 10 years of operation.

2.2 Cultural Center UFA-Fabrik in Berlin-Tempelhof

The Cultural Center UFA-Fabrik in Berlin-Tempelhof, home to various projects of urban ecology (see: www.ufafabrik.de) includes an integrated rainwater management project. As a first measure, most of the roofs were vegetated from 1983 to 1985. In 1994, a rainwater harvesting system was integrated. As a result, water from the green and conventional roofs is stored in a former underground waterworks station, along with runoff from street level.

The rainwater system at UFA-Fabrik has a total storage capacity of 240 m^3 in two cisterns. This is equivalent to 40 mm or 6.7% of annual precipitation of the catchment area. The system collects primarily "first flush" stormwater. By capturing the pollutants and nutrients associated with the "first flush" the UFA-Fabrik, which is situated on a separated sewer system, provides increased ecological benefits, by directing this polluted runoff to a modified constructed wetland for treatment. Collected rainwater is used to flush toilets and for irrigation. About 75% of rainwater used in the summer month is linked to irrigation. This rate of use, the large storage capacity for rainwater, and the greened roofs represent the integration of best management practices for the new water paradigm.

2.3 Demonstration Project "Adlershof Physik"

The Institute of Physics in Berlin-Adlershof is located in a research and office facility featuring several measures of sustainable architecture. It was designed by the architects Georg Augustin and Ute Frank (Berlin) following an architectural competition held in 1997. Rainwater is used to supply a façade greening system and central air-conditioning systems with evaporative exhaust air cooling. The water is harvested from the roofs and stored in five cisterns.

Research elaborating on the performance of the building is funded by the Berlin Senate of Urban Development, Section *Ecological Construction*. The project includes permanent monitoring of the water consumption of different plant species and performance of eight air conditioning units. Continuous monitoring has been carried out since 2004.

The façade greening system is evaluated to determine the importance of evaporation and shading on the overall energy performance of the building, including temperature and radiation measurements. Data collected from this project is used to calibrate simulations that are designed to predict performance and benefits in a range of different climatic conditions. This work will inform the design of future projects.

About 280 parameters are electronically harvested every minute. Primary systematic evaluation is based on the water parameters and their relation to energy dissipation. Additionally, 12 plant species and their requirements for maintenance (fertilization, plant protection) are monitored. Seven long-wave, short-wave and infrared sensors monitor the radiation concerning shading and reflection for each façade system. The building is not connected to stormwater

FIGURES 10 AND 11
Façade Greening System (priority 2; left); Artificial Rainwater Pond (Priority 3) Combined with Trough Infiltration for Stormwater Management (Priority 7; right)

sewers, reflecting one of the main goals of this decentralized system of rainwater retention and harvesting. Stormwater events from heavy rainfall are managed with an overflow into a small constructed pond in one of the courtyards, from which the water can evaporate or drain into the ground. To protect the quality of groundwater, this drainage is only allowed through surface areas covered with vegetation. Some of the roof surfaces are also extensively greened to assist in retaining and treating stormwater.

Evaporative Exhaust Air Cooling at the Institute of Physics

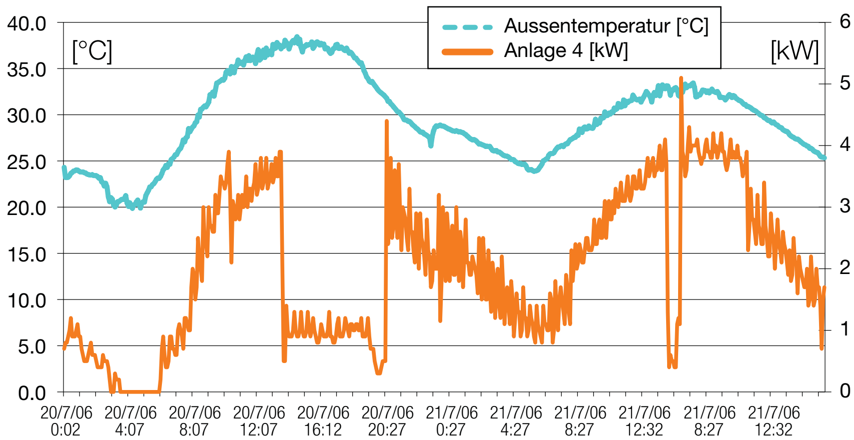
The German government's "climate protection program" defines a target of reduction of fossil fuel consumption by 40% by the year 2020. This ambitious goal is mainly based on the reduction of energy consumption in the building sector. However, the growing use of air conditioning powered by electric energy is in direct conflict with this target. In contrast with the desired target, it is estimated that energy consumption for cooling and ventilation will increase by 260% by 2020 (EECCAC 2003). Fortunately, a different approach to cooling, based on rainwater, can negate this conflict.

Air conditioning in the Institute of Physics is achieved through seven evaporative cooling units. These ventilation units use rainwater to cool air by the process of evaporation. First, rainwater is evaporated to reduce the temperature of the air leaving the building (Figure 12). This process has the capacity to cool exhaust air from 26°C to 16°C. In a second step, fresh air entering the building is cooled as it passes across a heat exchanger with cooled air on its way out. This process is sufficient to maintain indoor temperatures of 21-22 °C with outside temperatures of up to 30 °C. When outside temperatures exceed 30°C, indoor temperatures are maintained with the additional aid of conventional cooling systems based on absorption chillers.

Figure 13 demonstrates the results on performance of the systems studied. To evaluate the reduction in energy consumption, the conventional system was tested first with the evaporative cooling system switched off and then with it switched on. The resultant energy consumption of the conventional cooling system, in this case cold supplied by absorption chillers, indicates a decrease of 70%. The performance of 70% for the hottest day of the year suggests that the process is much more successful than expected. We can predict a reduction in energy consumption for cooling between 80 to 90% as an annual mean, compared to conventional systems. Additionally,

FIGURE 12
Adiabatic Exhaust Air Cooling with Rainwater in Seven Air Conditioning Systems (priority 4)

FIGURE 13
Evaluation of the Reduction in Energy Consumption When Switching the Evaporative Cooling System On and Off



the evaporation of (rain)water reduces the urban heat island effect, whereas conventional air conditioning systems exacerbate the problem by consuming electric energy and releasing heat outside, influencing neighboring buildings.

The advantage in using rainwater instead of tap water, which would also work, is that rainwater has no salt/ no lime, therefore a low electrical conductivity. When using potable water, two cubic meters are needed to evaporate one cubic meter and concurrently produce one cubic meter of sewage water. Using rainwater can conserve 50% in water volume and completely conserves wastewater (SenStadt 2010).

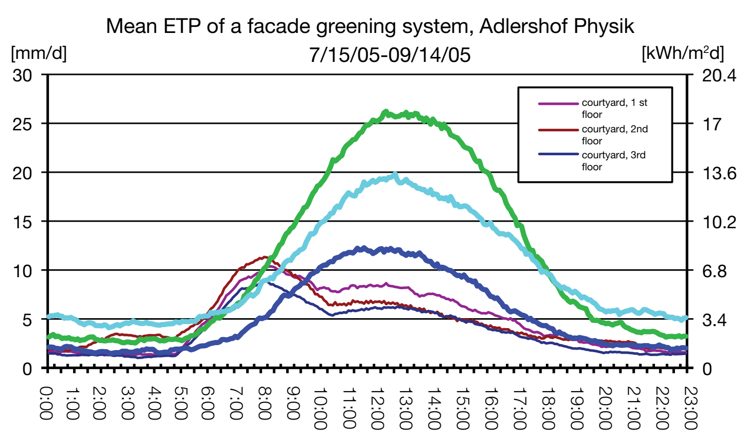
Due to evaporative heat loss of 680 kWh per cubic meter, even desalination by membrane reverse osmosis of seawater makes sense. The energy consumption of membrane seawater desalination decreased to a value of 7 kWh per cubic meter in the past years. In this case, evaporation implies energy savings of 100:1! Conventional compression cooling systems consume 200 to 350 kWh compared to the benefit of evaporation of one cubic meter of water. Heat releases of conventional cooling systems in the streets outside the buildings are 680 kWh plus an additional 200 to 350 kWh of electric energy consumption that is converted into heat as well. Evaporative cooling simply consumes heat.

Façade Greening System

Green façades were implemented at the Institute with two objectives: 1) to passively climatize the building through shading and solar radiation; and 2) to harness evapotranspiration to improve the microclimate inside and around the building. Plants provide shade during summer and, when defoliated in winter, the sun's radiation can lessen heating needs.

A total of 150 experimental troughs are organized in such a way that the water content is maintained at a constant level. Evapotranspiration demonstrates immediate feedback to water consumption. Since the troughs lack a facility for weighing, evaporation is determined by measuring the water supplied to the trough throughout the day. Figure 14 shows the mean daily evapotranspiration of this façade greening system, measured as water consumption. The real ETP is extremely high, likely because the plants have an optimized water supply and the surface area of the trough is small compared to the surface area of the plants. Mean evapotranspiration between July and September 2005 for the south face of the building was between 5.4 and 11.3 millimeters per day, depending on which floor the planters were located (Figure 14). This rate of evapotranspiration represents a mean cooling value of 157 kWh per day. Water consumption for the mature *Wisteria sinensis* increased up to 420 liters per day for 56 of the planter boxes. This represents a cooling value of 280 kWh per day for one of the courtyards. The courtyard has a size of 717 m², the greened façade a surface of 862 m².

FIGURE 14
Mean Evapotranspiration of the Façade Greening System In Mm/Day and Correspondent Cooling Rates



In selecting the climbing plants, emphasis was placed on choosing types that can grow in the extreme conditions of planter boxes. Of the various plants tested, *Wisteria sinensis* has proven to be the best. In addition to plants, a special system of irrigation and different substrates were also applied and studied. A factor in this selection was adequate capillary rise of water through the irrigation and substrate systems. Another aspect studied was providing of a layer of insulation to some of the planter boxes, to compensate for large shifts in temperature and especially to help protect against low winter temperatures. This comparison revealed that insulation can lead to significant differences in plant growth.

The combination of providing shade in the summer and permitting solar energy gain in the winter supported a further design for a technological development: the implementation of a simple translucent insulation system in arrangement with a vertical climbing plant structure. The overheating process of conventional translucent systems can be avoided, as evapotranspiration reduces the surface temperatures and improves the local microclimate. This system combines energy saving strategies and provides the natural water cycle; therefore, it includes the *"old"* climate change discussion and *"future"* strategies on mitigating global warming.

2.4 Watergy, a System for Water Treatment, Building Climate Control and Food Production

Watergy follows the development of a technology platform for the decentralized, basic supply of energy, water and food that can be used within a number of different applications (see www.watergy.de). The technological principle was proofed with two different prototypes between April 2003 and March 2006, and was funded by a European Union research project (NNE5-2001-683). In 2004, the first prototype was built for the purpose of greenhouse horticulture in Almeria, Spain. A second prototype was built in Berlin as a living- and office building with an attached façade-greenhouse.

The Watergy system combines solar collection with a mechanism for rainwater and greywater treatment. The building in Berlin (Figure 15) is based on the concepts of passive house insulation and solar-derived zero energy standards. A greenhouse located in front of a transparent wall on the southern face of the

FIGURES 15 AND 16 The Watergy prototype in Berlin- Dahlem (Germany), South-Facing Greenhouse Facade; the Watergy Prototype in Almeria (Spain), Cooling Tower in its Center (right)

building acts as a modified double façade. The air inside the greenhouse becomes heated by solar gain and also humidified by the plants. The warm air rises to the ceiling, where it is further heated and further humidified within a secondary collector element. The upper side of this collector leads to a chilled air duct that is located inside the building. Thus, when the warm air cools off it condenses and falls down through this duct, back into the greenhouse. Solar energy is stored in a 35 m³ tank of water, enough for heating the building through the wintertime.

The prototypes are supplied with rainwater and a condensation unit to regain the evaporated water. The process of evaporation and condensation creates excellent water quality and shifts large amounts of energy, the previously mentioned 680 kWh per cubic meters. The evaporation of harvested rainwater inside of the greenhouse represents priority 4 of Table 1. The system can be implemented in landscapes where natural precipitation is not sufficient for crop production. In Almeria the water demand for irrigation was reduced from 10 to 0.4 mm per day thanks to the recondensation of evaporated water in a cooling tower (Figure 16).

3. Conclusions

Rainwater harvesting measures that focus on evaporation rather than infiltration have tremendous potential to decrease the environmental impacts of urbanization. On a global scale, reduced evaporation on land causes increased temperatures (Kravčík et al. 2007). With this knowledge, the popular focus on reducing greenhouse gas emissions to mitigate global warming may be a fatal misinterpretation of environmental processes. Indeed, simulations of global climate changes continue to neglect the fundamental driving forces of the global climate: transpiration by vegetation and evaporation by land. Thus, the correlation between CO_2 and global temperatures in fact represent the processes of vegetation, namely photosynthesis and evaporation.

While we may all agree that human activities are causing desertification due to unsustainable land use (Schmidt 2010), the additional roles of water, soil and vegetation are still not in focus in the climate discussion. The global change in hydrology and its impact on the climate requests a new water paradigm (www.waterparadigm.org). Until recently, evaporation has always been defined and understood as a ***loss***. In fact, evaporation is the very ***source*** of precipitation. Drought is conventionally expressed as a result of rising global temperatures, but if we take this new perspective then increased aridity is the cause, not the result, of the global warming. Our intensive land use patterns are causing the planet to dry out (Ripl et al. 2007; Kravčík et al. 2007).

Rainwater harvesting measures can play a key supportive role as adaptation and mitigation strategies against the urban heat island effect and global warming.

When considering a close-up of the small water cycle, we may entertain the emergence of a new water paradigm. As part of this new paradigm, harvesting rainwater for evaporation would become a first priority in urban areas: not a single drop of water may leave urban surfaces simply to be funneled into sewer systems. Rather, harvested rainwater can be used for evaporative cooling via vegetation and/ or air conditioning units.

The research summarized above indicates that evaporation of water is the cheapest and most effective way to cool a building. It is known that one cubic meter of evaporated water consumes 680 kWh of heat. Thus, instead of conventional cooling systems (old cooling approach) which releases heat outside the building, produces additional heat, and consumes energy, the evaporation of water simply consumes heat (new cooling paradigm). In this way, energy is released when water vapor condenses on any given surface, or in the atmosphere. Condensation in the form of clouds in the atmosphere represents the primary energy loss by the earth into space.

Acknowledgements

The author would like to express sincere thanks to Brigitte Reichmann (Department of Ecological City Construction, Berlin Senate) for organizing and financing the innovative project in Berlin-Adlershof. Many thanks to Christine Thuering (Chlorophyllocity) who improved my English.

References

EECCAC (Energy Efficiency and Certification of Central Air Conditioners). 2003. Report for the DGTREN of the Commission of the EU, 2001, 1: 52.

Gerlich, G., and Tscheuschner, R.D. 2007. "Falsification of the Atmospheric CO_2 Greenhouse Effects within the Frame of Physics." http://arxiv.org/abs/0707.1161; http://arxiv.org/pdf/0707.1161v3; http://www.tsch.de.

GTZ (Deutsche Gesellschaft fuer Technologische Zusammenarbeit). 2007. *Reducing Emissions from Deforestation in Developing Countries.* Eschborn: GTZ. http://www.gtz.de/de/dokumente/en-climate-reducing-emissions.pdf.

Kiehl, J. T., and Trenberth K.E. 1997. "Earth's Annual Global Mean Energy Budget." *Bulletin of the American Meteorological Society:* 197–208.

Kravčík, M., Pokorný J., Kohutiar J., Kováč M., and Tóth E. 2007. "Water for the Recovery of the Climate - A New Water Paradigm." Municipalia. http://www.waterparadigm.org.

Ripl, W., Pokorny J., and Scheer H. 2007. "Memorandum on Climate Change, the Necessary Reforms of Society to Stabilize the Climate and Solve the Energy Issues." Berlin. http://www.aquaterra-berlin.de.

Schmidt, M. 2005. "The Interaction between Water and Energy of Greened Roofs." Proceedings of the "World Green Roof Congress," Basel, Switzerland, September 15–16.

Schmidt, M., H. Diestel, B. Heinzmann, and H. Nobis-Wicherding. 2005. "Surface Runoff and Groundwater Recharge Measured on Semi-Permeable Surfaces." In *Recharge Systems for Protecting and Enhancing Groundwater Resources,* Proceedings of the 5th International Symposium on Management of Aquifer Recharge ISMAR5, 190–193, Berlin, Germany, June 11–16, 2005. http://unesdoc.unesco.org/images/0014/001492/149210E.pdf.

Schmidt, M. 2009. "Global Climate Change: The Wrong Parameter." Proceedings of Rio9, "World Energy and Climate Event," 167–176, Rio de Janeiro, Brazil. http://www.rio9.com/programme/Book_of_Proceedings/28_ES_Schmidt.pdf.

Schmidt, M. 2010. "A New Paradigm in Sustainable Land Use." *Topos* 70, *Callwey Verlag*.

SenStadt. 2007. "Environmental Information System, Berlin Digital Environmental Atlas, Map 02.13 Surface Runoff, Percolation, Total Runoff and Evaporation from Precipitation." Senatsverwaltung für Stadtentwicklung. http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/edb213_05.htm.

SenStadt. 2010. "Rainwater Management Concepts: Greening Buildings, Cooling Buildings. Planning, Construction, Operation and Maintenance Guidelines." Senatsverwaltung für Stadtentwicklung, 72. http://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/download/SenStadt_Regenwasser_engl_bfrei_final.pdf. [Accessed 31 August 2010].

Trenberth, K. E., Fasullo J.T., and Kiehl J. 2009. "Earth's Global Energy Budget." *Bulletin of the American Meteorological Society:* 311–323.

UBA (Umwelt Bundes Amt). 2008. "Environmental and Spatial Planning: Reduction of Land Use." UBA, http://www.umweltbundesamt.de/rup-e/flaechen/index.htm.

CHAPTER 14

Characterizing the Response of Buildings to Climate Change: The Issue of Overheating

Tristan Kershaw,* David Coley

Summary

Many buildings currently demonstrate levels of overheating close to the maximum allowed by the building regulations of the countries in which they are located. Therefore there is the potential that such buildings will clearly breach the regulations under the climatic conditions predicted as a result of climate change. To examine the problem, weather files indicative of possible future climate were created and applied to a variety of buildings. Using numerous combinations of buildings and weather scenarios, the modeling demonstrated that the projected levels of climate change engender a linear response in the internal temperature of the buildings. The resultant constant of proportionality that this implies has been termed the 'climate change amplification coefficient'. This paper demonstrates that optimization of the climate change amplification coefficient during the design process of a new building will promote the adaptation of architectural design to the effects of climate change and thereby improve resilience.

*Corresponding author: T.J.Kershaw@exeter.ac.uk

1. INTRODUCTION

There is now an overwhelming body of scientific evidence suggesting that climate change is an urgent and serious issue. Predictions of the world's climate point to an increasingly warmer world, with greater warming across land and away from the equator (IPCC 2007). Predictions contained within the IPCC's fourth assessment report (AR4) indicate mid-latitude mean temperature rises over land of ~4°C (under the A1FI scenario) (IPCC 2007). However, recent research (Anderson and Bows 2008) shows that current emission trends could lead to actual temperature increases which are far higher than predicted by the A1FI scenario. This implies that several highly populated regions not acclimated to high temperatures will be exposed to a very different summertime experience. In the absence of any human modification of climate, temperatures such as those seen in Europe in 2003 have been estimated to be 1-in-1,000 year events. However, modeling by the Hadley Centre shows that, by the 2040s, a 2003-type summer is predicted to be about average (Stott 2004) and this will clearly have a great impact on the energy consumption of air conditioned spaces and the thermal comfort within naturally ventilated ones. In order to assess the scale of the problem there is the need to understand the sensitivity of the internal environment of buildings to changes to climate, and the sensitivity of the occupant, particularly of vulnerable groups. Here, the focus is on the former, with an attempt to quantify the response of all naturally and mechanically ventilated, non air-conditioned, buildings to changes to summertime temperatures. A reliance on air-conditioning, rather than careful architectural design will exacerbate the problem of climate change, due to the implied increase in carbon emissions. Given a quantitative scale of response, it should be possible to assemble risk registers of buildings and occupants, to improve the design of new buildings, and initiate the refurbishment of existing ones such that they are more resilient to a changing climate.

It seems natural to expect the response of a building to a perturbation in climate to be complex, with the functional form of the response depending on the degree of climate change and whether this is mainly a result of changes in, for example, wind rather than sunlight or air temperature rather than humidity, and on the architecture, construction materials, ventilation strategy and controls present. The existence of such a complex response function would make it difficult to discuss in any simple way the relative benefits of one design over another, or even characterize the response of a building with a single measurable statistic. For example, it might be possible that one design demonstrates little change in internal temperature for small perturbations to the external climate, but then a large and rapid response for greater perturbations, and that another design might show the opposite response. In such a situation it would be very difficult to draw any simple conclusions as to which design is likely to perform better under any particular climate scenario. Instead, a substantial amount of costly computer modeling would be needed to report a time series of changes given a time series of exact predictions of climate change within the urban environment. Climate science has yet to be able to give such predictions with the required accuracy, and even if it could, building design might still be an issue. For example, one building design outperforms another until 2040 and then underperforms the alternative design. Again, the potential complexity of the relationship between the building and the external environment makes it very difficult to draw general conclusions and drive the adaptation agenda forward.

This research investigates the form of the response function of a large number of buildings given a range of predictions of future climate. From this work it is possible to derive a single set of coefficients that fully describe the expected response of any design to any reasonable amount of climate change. Further, these coefficients can be used to establish a definition of climate change resilience within architectural dialogues and set minimum performance standards within building regulations and codes, with the aim of promoting adaptation to a changing climate.

2. APPROACH

2.1 Prediction of Future Weather

Given statements of future climate by the IPCC and others (Murphy 2000) a time series of typical future weather can be assembled in one of several ways, for instance by using recorded historical data for locations whose current climate matches that predicted for the location in question. This has the downside that certain weather variables such as hours of daylight, will be incorrect. Other methods include interpolating (in space and time) the time series produced by a global circulation model, or to run a fine (in space and time) regional climate model connected to a global circulation model. All these methods have advantages and disadvantages, which are discussed in more detail in Belcher (2005).

Belcher (2005) have developed a methodology for transforming historic weather files into future weather years representative of different climate change scenarios by the use of a set of simple mathematical transformations. The simplicity of this method has made it attractive to building scientists. In this method hourly weather data for the current climate is adjusted with the monthly climate change prediction values of a regional climate model (in the case of the UK, the output from UKCIP02 (UKCIP 2002)). This methodology is termed 'morphing'.

The morphing process has the advantage that it starts from observed weather from the location in question, the variables output are likely to therefore be self-consistent and it is simple to achieve given the resources available to building scientists. However, it doesn't allow for fundamental changes in the weather, with for example, weather systems following identical trajectories across the landscape. Table 1 shows summary statistics for some of the future weather time series created using morphing and used in this work. The IPCC AR4 (2007) shows the upper boundary of the A1F1 scenario to be 6.4°C. However, current emissions may exceed even the A1F1 scenario (Anderson 2008), making it prudent to include more extreme climate change. While the extreme scenarios may seem unrealistic, with the Hi++ scenario[1] predicting an increase of nearly 10°C in mean temperature, this represents an upper bound in the absence of the more up to date probabilistic scenarios of UK Climate Projections 2009 (UKCP09) (which at time of writing have not yet been released). This scenario is designed to lie in the tail of the UKCP09 distributions and account for missing climate feedbacks in IPCC AR4.

TABLE 1
Example Statistics for Historic and Future Weather for London

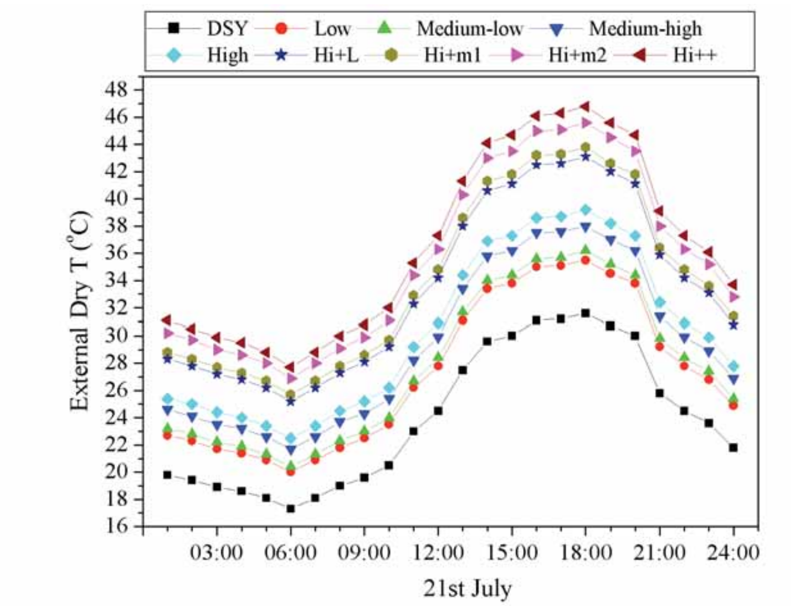
Scenario	Min Dry T(°C)	Max Dry T (°C)	Mean Dry T (°C)	Mean T (°C)
Historic TRY	1.10	30.10	14.71	-1.14
Historic DSY	0.00	33.60	15.85	0
Low	1.50	37.70	18.42	2.57
Medium-low	1.80	38.40	18.85	3.00
Medium-high	2.50	40.30	20.07	4.22
High	3.00	41.50	20.83	4.98
Hi+L	4.60	45.60	23.40	7.55
Hi+m1	4.80	46.30	23.83	7.98
Hi+m2	5.60	48.30	25.05	9.20
Hi++	6.00	49.50	25.81	9.96

Table 1 shows example statistics for summertime dry bulb temperature (Dry T) for the test reference year (TRY) and the design summer year (DSY) (Levermore 2006) for London. These files are currently used for energy and overheating analysis, respectively, for buildings in the UK, and characterize a typical year (the TRY) and a hot but non-extreme summer (the DSY) chosen from a 23-year cycle. Also shown are statistics for future weather year's indicative of the 2080's based

[1] Details of the construction of these custom scenarios can be found in Coley (2010).

upon the emissions scenarios of the IPCC (2007) and UKCIP (2002) created using the morphing process. The four extreme scenarios Hi+L, Hi+m1, Hi+m2 and Hi++ were created by performing the morphing procedure twice. Figure 1 shows traces of external air temperature for a typical summer day for the DSY reference year and the different climatic scenarios for the 2080's time slice. Note how the morphing procedure preserves the shape of the diurnal temperature swing, an indication that the underlying weather patterns have not been altered.

FIGURE 1
Plot of External Dry T for a Typical Summer's Day for Different Climatic Scenarios



2.2 Thermal Simulation

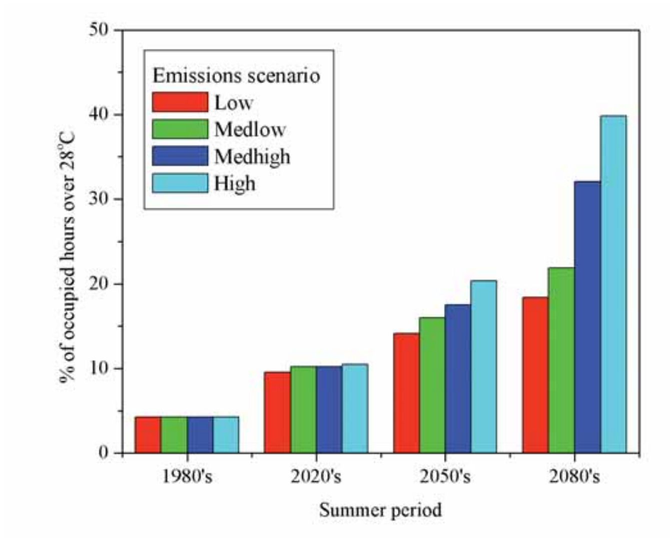
Over 1000 different combinations of future weather, architecture, ventilation strategy, ventilation type (natural, mechanical and buoyancy driven stack ventilation), thermal mass, glazing, U-value and building use (house, school, apartment, or office) were studied. In addition, more extreme predictions of future weather were included (see Table 1) in order to ensure the results would remain valid if future climate modeling work or measurements indicate different climatic futures than currently predicted by UKCIP. Thermal simulations of the different architectural designs were performed for the four UKCIP emissions scenarios for the three time slices (2020's, 2050's and 2080's) and also for the four extreme scenarios in the 2080's timeslice. Each building was modeled using an industry-standard dynamic simulation package (Integrated Environmental Solutions Virtual Environment), which models radiative, conductive and convective heat exchange between building elements and the internal and external environment, and includes dynamic representations of occupancy densities, solar gains, air densities, air flow and heating systems.

Since the morphing procedure does not change the underlying weather patterns, the work was repeated using a series of (unmorphed) historic weather records for various parts of the world that might be considered to represent the possible range of UK future climates, including some extreme changes in the underlying weather. By definition, these demonstrate very different weather patterns and correlations between weather variables. Coley (2010) noted that there is a clear linear response between the response of the internal environment and perturbations to the external environment as a result of climate change. The gradient of this linear response dubbed the climate change adaptation coefficient gives an indication of how resilient a given building is to climate change. In essence they indicate the degree of amplification (or suppression) the architecture of a building is capable of. So if, for example, $C_T = 1.5$ for a building, a prediction of 2°C rise in mean summertime temperature from a climate model implies with a high degree of accuracy a 3°C rise in mean summertime internal temperature.

3. RESULTS

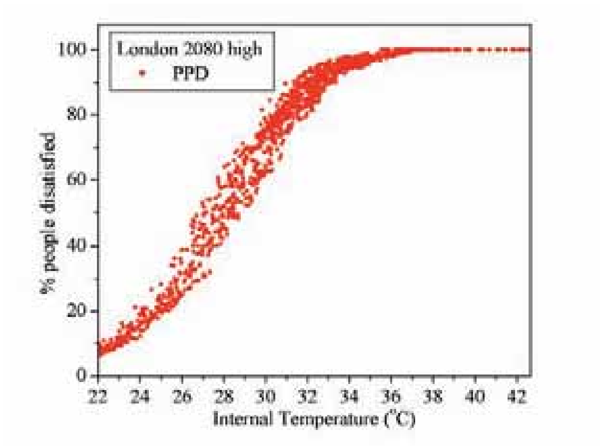
The thermal simulations show that all the buildings studied pass the UK building regulations using the DSY reference year. However, with the use of sequentially more aggressive climate change scenarios, increasing numbers of buildings start to fail. Figure 2 shows how the percentage of (summertime) occupied hours >28°C (a metric used to indicate overheating in the UK building regulations) varies for the different UKCIP02 emissions scenarios at different time slices for a single design of a school. While the school does not overheat using the DSY (1980's time slice) the design fails building regulations from the 2020's onwards for all the emission scenarios studied, with a peak of over 40% of occupied hours >28°C in the 2080's. This degree of failure is by no means uncharacteristic with some design variants showing over 90% of occupied hours >28°C by 2080. Typically the problem of overheating quickly escalates with the use of more aggressive climate scenarios, a trend which is consistent across all the designs of buildings studied.

FIGURE 2
Percentage of Occupied Hours Over 28°C for Different Emissions Scenarios and Time Slices



Clearly the above situation is unacceptable and will have a profound effect on the thermal comfort experienced within the occupied spaces. As the internal air temperature within the building increases it becomes more difficult for the human body to cool itself. A metric for measuring thermal discomfort is the percentage of people dissatisfied (PPD) (Fanger 1970). Figure 3 shows the PPD for an open plan working space within an office block sited in London (high emissions scenario 2080's time slice). Each point represents the hourly average air temperature in the space and the resulting PPD for the whole summer period. The graph shows that as the internal air temperature approaches 37°C all of the building occupants are experiencing thermal discomfort. It is clear from comparison of Table 1 with Figure 3 that under climatic scenarios in which the external air temperature is likely to exceed 37°C nearly all people will be experiencing thermal discomfort. Unless the building can successfully modify the internal climate without resorting to air-conditioning, the problem of building emissions will be exacerbated.

FIGURE 3
Percentage of People Dissatisfied (PPD) for an Open Plan Office Space Under High Emissions Scenario for the 2080's



4. CLIMATE CHANGE AMPLIFICATION COEFFICIENTS

It is possible to characterize the degree of climate change by the perturbation to the external air-temperature (Dry T) as shown in Table 1 and hence the effect on a given design of building by the change in internal air-temperature. A comparison of external mean or maximal temperatures against the corresponding internal temperature for different perturbations (climate scenarios) yields with a high degree of accuracy a linear relationship. This is surprising because it might be assumed that the relationship is a complex sum of the different heat flows within the building structure. Figure 4(a) shows a subset of the results for five buildings for all the climate scenarios studied. The following observations are true for all the designs:

- The form of the response to the perturbation of the weather file is always linear, regardless of the architecture, construction, ventilation type or use of the building;
- Different buildings demonstrate different gradients ranging from 0.75 to 1.85;
- The intercept of any two regression lines is always at negative values of the perturbation (i.e. to the left of the graph), implying that any building which shows a lower mean or maximum internal temperature than another in the current climate will continue to do so for future climates.
- From the previous two points it can be concluded that the response to a perturbation of climate can be characterized solely by the gradient of the regression line—the intercept is not relevant. However, for buildings with large internal gains the internal temperature is higher (the intercept is greater) but the

gradient is unaffected (internal gains have no affect on the buildings response to climate change), indicating that comparison of C_T should be restricted to buildings with similar uses and internal gains. The exact relationship between C_T and the intercept requires further investigation.

- Some designs show gradients greater than unity, others less. A value greater than unity indicates that the building amplifies the effects of climate change, while a value less than unity means that it suppresses the effects of climate change.
- There is no advantage in multiple simulations of a building with a range of carbon and climate scenarios. Two simulations are enough to identify the gradient and therefore the response of the building to other scenarios can simply be calculated from the gradient.

Mathematically, we can see that we have two constants (C_{Tmean} and C_{Tmax}) that represent the propensity of any design to overheat given a known perturbation to the current climate:

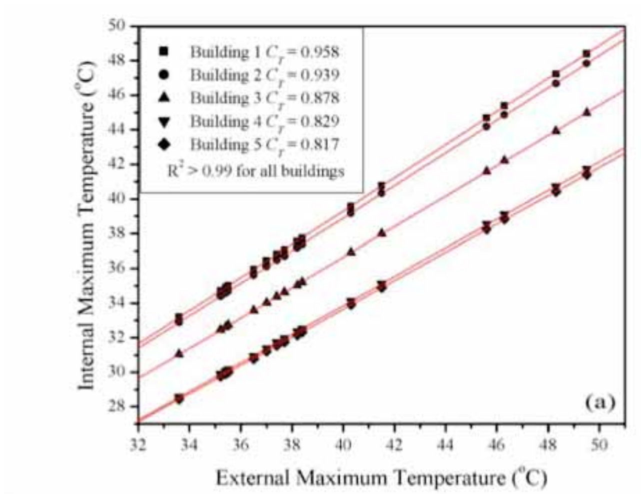
$$C_{T_{mean}} = \frac{\delta T^{\text{internal}}_{\text{mean}}}{\delta T^{\text{external}}_{\text{mean}}} \text{ and } C_{T_{max}} = \frac{\delta T^{\text{internal}}_{\text{max}}}{\delta T^{\text{external}}_{\text{max}}},$$

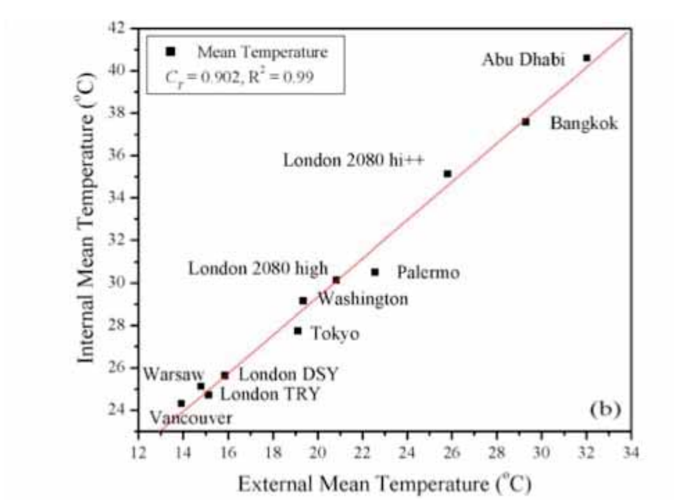
where *mean* and *max* refer to the mean or maximum temperature observed either in the weather file (*external*) or within the building (*internal*). We term such constants *climate change amplification coefficients* (C_T), and presumably other such descriptors could be identified (for example changes in cooling demand for air conditioned buildings). The correlation coefficient (R^2) of C_T exceeds 0.997 for all the buildings studied.

C_{Tmean} and C_{Tmax} fully describe the response of the maximum and mean temperature of any design to a changing climate and the existence of such coefficients of proportionality demonstrates that the concern expressed in the introduction about the potential complexity of the response function is invalid. We believe that such coefficients are highly suitable for describing the response and relative benefits of a series of design alternatives. Because these two coefficients appear to be able to take values either side of unity, it is tempting to describe buildings that have values less than one, as *resilient*, and those with values greater than one as *non-resilient*. However, this simple binary classification ignores the potentially serious consequences of higher indoor temperature for vulnerable groups, where even a mild increase in temperature can be fatal if it is sustained over several days with a minimal diurnal cycle.

It might be thought that one possible explanation for the linear response can be found in the form of the perturbations used in the morphing process, detailed in Belcher (2005). However, as mentioned above, another way to produce a time series indicative of future weather is to use historic weather from a location that has a climate similar to that predicted for the future climate in the location of interest. In general, such time series diverge far more from the historic weather in the location of interest and cannot be represented by shift and stretch functions. A subset of the buildings was simulated with historic weather files from other locations; the results for one building are summarized in Figure 4(b). Again, such perturbations engender a linear response, although with a lower correlation coefficient.

FIGURE 4
(a) Plot of the response of five buildings to different climate change scenarios described by their perturbations to external maximum air temperatures (data shown for 5 different domestic buildings). (b) Plot of the response of one building to different climates derived from historic weather files of selected location (data shown for a typical office block).





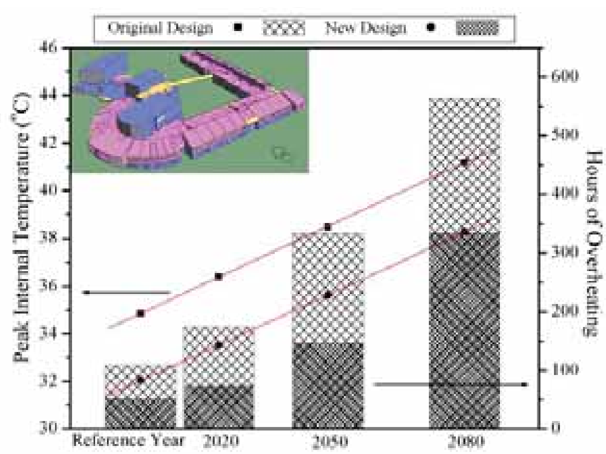
4.1 Case-Study

Using a highly detailed thermal model (Figure 5 inset) of a newly built school in the UK which overheats and demonstrates low thermal comfort it is shown that the use of climate change amplification coefficients could have produced a building that not only fares better in the current climate but also under the effects of predicted future climate change.

Typically the DSY reference year used to model a building for overheating analysis is the 3rd hottest observed summer period between 1983 and 2004. Modeling the building as constructed using the entire base set of observed summers in the same period shows that, while the reference year is, on average, the 3rd hottest in terms of external air temperature, it is the 6th hottest in terms of mean internal air temperature and hours of overheating (>28°C), falling to 8th if 2005/06 are included. This is not surprising given that the internal temperature of a building is dependent on other weather variables in addition to air temperature. Thus, while the modeled design just passes the building regulations, a good proportion of the observed weather years from which the reference year is chosen cause the building to fail. It is clear that the DSY reference year is outdated and does not take into account recent changes in climate, hence it is unsurprising that the building overheats in the current climate and demonstrates low thermal comfort. Calculation of the climate change amplification coefficient for different design variations would have allowed an estimate of how the building would respond to different climatic conditions without having to run a large number of simulations.

A climate change amplification coefficient C_T can be calculated using a minimum of two simulations of a building (four are used in this case study for clarity) and can give an estimate of how that design will behave for any given amount of climate change irrespective of weather patterns. This means that the outdated snapshot of weather and climate represented by the reference year can be replaced by a distribution of possible climatic scenarios by performing a single extra simulation, instead of many simulations of different climatic futures. By altering design features and ventilation strategies of the building model to minimize C_T it is possible to create a building that should perform well for many years to come. Using the model of the school as an example, several different variations of the design were simulated and C_T calculated. The value of C_T for the school as constructed is 1.031 for the mean (0.761 for the maximum) internal air temperature (averaged across all rooms in the school). By increasing the admittance of some of the internal surfaces and altering the ventilation strategy to include night cooling to restore the coolth of the internal structure, it is possible to reduce the values of C_T to 1.009 for mean (0.749 for the maximum) internal temperature (C_{Tmax} is the line gradient in Figure 5). While these reductions may not seem large this translates to a reduction in the predicted mean internal temperature of the school of 1.5 °C (reduction in maximum of 2.9 °C) and a reduction of 100 hours of overheating by 2020 (Figure 5). Moreover, the building would still pass the building regulations in the 2020's time slice, indicating that if the building had been constructed with these modifications then it would not currently overheat and would still be usable for many years to come. Such large reductions in the increase of internal temperature as a result of climate change due to the reduction in C_T can be explained by examination of the trend lines in figure 5. The time scale represented by the *x*-axis can be replaced by one of change in external temperature allowing comparison between figures 4 and 5. The intersection of the two lines plotted in figure 5 is far off the left hand side of the graph, therefore a small change in the gradient can produce a large change in the internal temperature.

FIGURE 5
Plot of Peak Internal Temperature and Hours of Overheating (both averaged over the entire school) for Different Time Slices Under The High Emissions Scenario.



Inset: a rendering of the thermal model of the school used.

5. CONCLUSIONS

Driven by questions of increased morbidity and mortality of vulnerable groups, particularly in mid-latitude cities as the climate warms (Vandentorren 2004), the general form of the response of the internal environment within buildings to perturbations in climate has been studied. The response, as measured by the change in mean, or maximum, internal summertime temperature, to a change in mean or maximum external temperature, would appear to be linear, regardless of whether the perturbations are created by simple mathematical transformations of historic weather, or by the use of historic weather from other, warmer cities as proxies.

We have termed the resultant constants of proportionality *climate change amplification coefficients* (C_T), and suggest that the estimation of these for new or existing buildings will allow more rapid thermal modeling of buildings with respect to climate change, the design of more resilient buildings, cost-benefit analysis of refurbishment options and the rational assembly of at-risk registers of building occupants. Furthermore, this paper demonstrates that minimizing the climate change amplification coefficient, $C_{T,}$ during the design process can be used to adapt a building to the effects of climate change, reducing overheating and improving thermal comfort.

References

Anderson, K., and Bows A. 2008. "Reframing the Climate Challenge in Light of Post-2000 Emissions Trends." *Philosophical Transactions of the Royal Society A* 366: 3863–82.

Belcher, S. E., Hacker J. N., Powell D. S. 2005. "Constructing Design Weather Data for Future Climates." *Building Services Engineering Research & Technology* 26: 49–61.

Coley, D., Kershaw T. 2010. "Changes in Internal Temperatures Within the Built Environment as a Response to a Changing Climate." *Building and Environment* 45: 89–93.

Fanger, P. O. 1970. *Thermal Comfort*. Copenhagen: Danish Technical Press.

IES (Integrated Environmental Solutions). http://www.iesve.com/content/ [Accessed April 14, 2009].

IPCC (Intergovernmental Panel on Climate Change). 2007. "Intergovernmental Panel on Climate Change: Fourth Assessment Report." http://www.ipcc.ch. [Accessed April 14, 2009].

Levermore, G. J., and Parkinson J. B. 2006. "Analyses and Algorithms for New Test Reference Years and Design Summer Years for the UK." *Building Services Engineering Research & Technology* 27: 311–25.

Murphy. J. 2000. "Predictions of Climate Change over Europe using Statistical and Dynamical Downscaling Techniques." *International Journal of Climatology* 20: 489–501.

Stott, P. A., Stone D. A., Allen M. R. 2004. "Human contribution to the European heatwave of 2003." *Nature* 432: 610–4.

UKCIP. 2002. *UKCIP02: Climate change scenarios for the United Kingdom*. http://www.ukcip.org.uk. [Accessed April 14, 2009].

UKCIP. Unpublished. "*UKCP09*". http://www.ukcip.org.uk. [Accessed April 14, 2009].

Vandentorren, S. et al. 2004. "Mortality in 13 French Cities During the August 2003 Heat Wave." American Journal of Public Health 94: 1518–20.

CHAPTER 15

Comparative Study of Energy and Carbon Emissions Development Pathways and Climate Policy in Southeast Asian Cities

Aumnad Phdungsilp*

Summary

The United Nations has estimated that about half of the 6.5 billion world population currently lives in cities. Moreover, an additional 1.8 billion people will move to urban areas by the year 2030. Understanding the relationships between energy use pattern and carbon emission development is crucial for estimating future scenarios and can facilitate mitigation and adaptation of climate change. This paper investigates the development pathways on selected Southeast Asian cities, including Bangkok, Hanoi, Jakarta and Manila, which are major cities in the region in terms of energy consumption, carbon emissions, and climate policies. The paper investigates the development of energy and carbon emissions, and climate change mitigation strategies of the selected case studies. In addition, the paper attempts to estimate the energy consumption and associated carbon emissions. Then, it compares overall patterns of selected cities and analysis of the climate policies.

Key Words: Carbon Emissions, Climate Policies, Energy Consumption, Southeast Asian Cities

*Corresponding author: aumnad@dpu.ac.th

1. INTRODUCTION

The United Nations has estimated that about half of the world's 6.5 billion people currently live in cities. Moreover, an additional 1.8 billion people will move to urban areas by the year 2030. Southeast Asia contributed 12% of the world's total greenhouse gas (GHG) emissions in 2000, amounting to 5,187.2 Mt CO_2-eq, including emissions from land use change and forestry. The region's total emissions increased 27% during 1990-2000, faster than the global average rate of increase. On a per capita basis, the region's emissions are considerably higher than the global average, but are still relatively low when compared to developed nations. Furthermore, the region's GHG emissions from the energy sector grew by 83% during the same period; the highest growth rate among three major sources of emissions (i.e. land use change and forestry, energy and agriculture) (ADB 2009).

Cities are both drivers and targets of climate change. Cities are the engines of economic development of a country, as well as centres of key activities that drive changes in the carbon cycle and climate system. Despite the importance of cities, they have not been a unit of analysis for energy and carbon emissions in past decades. This is particularly true for Southeast Asian cities where rapid economic growth has led to rapid increases in energy consumption and carbon emissions. As a consequence of urban expansion, Southeast Asian cities will require an enormous amount of resources and will emit more emissions.

Understanding the relationship between energy use pattern and carbon emissions is crucial for estimating future scenarios, and can facilitate mitigation and adaptation to climate change. The main research questions are: How have past and current trends in energy consumption and carbon emissions developed over time in major Southeast Asian cities? What are the future scenarios of the target cities? How do city officials respond regarding climate change policies? What policy measures have been implemented to influence mitigation in selected cities? To address these questions, a comparative study of development pathways for select Southeast Asian cities in terms of energy consumption, carbon emissions, and climate policies, has been conducted. The study is focused on four cases: Bangkok, Hanoi, Jakarta and Manila, which are major cities in the region and can contribute to large extended energy-saving opportunities and carbon emission reductions as well as regional development.

The paper investigates a range of socio-economic aspects that influence energy consumption and energy-related CO_2 emissions, and energy and climate policies. In addition, the paper attempts to estimate future scenarios of energy consumption and associated CO_2 emissions. The study focuses on an analysis of the development pathways of energy consumption and energy-related CO_2 emissions. Then, it compares overall patterns of the selected cities.

Main findings of the case studies can contribute to underpin more efficient energy utilisation, carbon emission reductions, and enhancing sustainable development at city, national and regional levels. This study can also help to understand ongoing processes and develop means on how to react strategically to climate change.

2. DRIVING FACTORS IN ENERGY CONSUMPTION AND EMISSIONS

In principle, energy use and associated emissions in a city are generated by three kinds of activities. The first type is produced through direct energy consumption or direct emissions within the boundary of a city itself (e.g. gasoline or diesel combusted by vehicles). The second type is indirect energy consumption or indirect emissions, which is encompassed those types of energy use in a city where energy is used inside a city with the actual emissions taking place outside its boundary (i.e. electricity generation). The third type of activity is embodied energy or embodied emissions. This activity is due to energy use and environmental emissions taking place outside of the city to produce goods and services consumed within the city (Dhakal 2008).

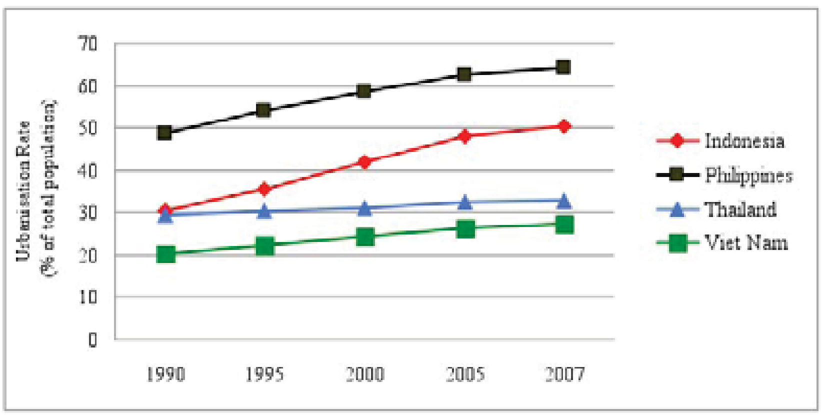
Factors driving energy consumption and associated emissions in cities have been interpreted differently among research communities. Engineers typically look at the contributions of various energy sectors (i.e. residential, commercial, industrial and transport sectors) as well as the energy mix in an energy system. Economists see the energy use and emissions linkages to income, elasticity, market role, price, etc. Social scientists see the drivers from a wider perspective. Dhakal (2008) has summarised different approaches to explain such drivers as following.

Emissions = sum (sectoral and subsectoral disaggregations)
Emissions = f (emission/energy, energy/income, income/person, population)
Emissions = f (economic growth, price signal, externality, market mechanism)
Emissions = f (population, organisation, environment, technology, institutions, culture)
Emissions = f (mobility, shelter, food, lifestyle)

A strong correlation between emissions, population and gross domestic product (GDP) reflects the importance of population and economic growth as emission drivers. Figure 1 presents an overall picture of urbanisation rate in selected Southeast Asian countries. It is projected that in the year 2020 the population in Bangkok, Hanoi, Jakarta and Metro Manila will reach 7.76, 5.78, 20.77 and 13.4 millions, respectively (ADB 2008).

Previous studies have used decomposition analysis to analyse the importance of population, income, energy intensity and fuel mix shifts in shaping energy-related emission trends. A comprehensive global study on factors contributing to CO_2 emissions can be found from Baumert et al., 2005. It should be noted that the drivers of CO_2 emissions are very complex and multifaceted. These drivers are raising the challenge to greater in-depth analysis, particularly at a city-scale.

FIGURE 1
Trends of Urbanisation Rate in Selected Southeast Asian Countries



Source: UNESCAP 2008.

In Southeast Asian cities, the major driving forces behind energy consumption and CO_2 emissions are related to urban demographic changes, income level and lifestyle, socio-economic development, urban spatial structure and transportation system, energy technologies, and local climate factors. An understanding of these factors is essential to formulating policy measures in achieving co-benefits of reducing energy consumption and impacts of climate change. Some previous studies discussed the drivers that influence energy consumption and emissions from Asian cities, for example see Dhakal 2004; 2008. Impacts of some of these drivers are well established while others are not clear. Furthermore, some drivers are also dependent on location (i.e. local climate, geography, culture, etc.); therefore, an in-depth analysis of a particular city is required for a full understanding of driving factors.

3. ENERGY AND CLIMATE POLICIES

Cities in developed countries tend to make comprehensive energy and climate policies locally and in many cases have specific emission targets. Europe has been at the forefront of the attempts to reduce CO_2 emissions from cities. Many European cities are much ahead in implementing local climate policies compared with other regions.

Southeast Asian cities are likely influenced by the central government decision regarding energy and climate policies. Some cities, such as Bangkok, are raising energy and climate awareness to the residents and some cities are in the development stage. It is found that in many cases, they often show climate policy linkages through co-benefits in relation to activities in energy efficiency, energy conservation, urban air pollution and health, and land transport management. Also, many cities are interested in developing energy and climate projects for generating local revenue through Clean Development Mechanism (CDM) and selling Certified Emission Credits (CERs) to their parties. Most of the urban projects are related to improving energy efficiency, fuel switching, and waste management (Dhakal 2008).

Energy and climate policies are challenging issues, particularly at the city-scale since most of the relevant policies are designed at the national level. Currently, comprehensive policy with a focus on climate mitigation does not exist at a city level in Southeast Asia, but some cities in developed Asian nations, such as Japan (Tokyo and Osaka) and Korea (Soul), have started formulating such policies. At a national level, some Southeast Asian countries have already introduced and implemented various policies in meeting their energy and development goals, and each country has developed a specific policy framework or integrated climate concern in the overall energy and development policy framework (Table 1). It should be noted that the focus in this study is based on the existing legal measures. The study found that each case studied country has developed its own national plan and strategy for climate change and has established an agency for climate policy.

Southeast Asia has considerable potential to harness renewable resources. Indonesia, the Philippines and Thailand have elaborated specific renewable energy policy frameworks (see Table 1). Energy security is very prominent in the policy goals of these countries though environmental protection, energy access and investment promotion goals are also considered important. These policy goals reflect the concern of growing dependence on imported energy and environmental issues related to power generation, particularly in the Philippines and Thailand. In the Philippines, under the Philippine Energy Plan, the use of new and renewable energy sources is seen as significant in contributing to electricity generation. Thailand has developed the Alternative Energy Development Plan, which covers a wide range of power generation and heat production from renewable energy resources. Thai government target is to increase the share of renewable energy to 8% by 2011.Recently, Thailand has announced a new renewable energy plan, which aims for energy from renewable sources to constitute 20% of final demand by 2022. In Vietnam, the Energy Law aims to improve energy efficiency and promotes the development of renewable sources. Renewable energy development is pursued within the context of improving energy access in rural areas. Vietnam has also recognised the relevance of renewable energy development as a least-cost option to increase electricity access in remote and isolated regions (ADB 2009).

The transport sector has high potential to reduce CO_2 emissions and improve urban air quality in Southeast Asian cities. Policies in Thailand to mitigate emissions from transportation include the development of a master plan in large cities, promoting the mass transit systems in Bangkok, encouragement of car pools, retrofitting and improvement of engine efficiencies, and promoting the use of natural gas in vehicles. Indonesia considers the development of mass rapid transportation as an important measure to reduce emissions in urban areas. The Indonesian government has developed the strategic plan for the transportation sector in response to climate change. In the Philippines, Road Transport Patrol Programme was launched to promote efficient use of fuel. Vietnamese government plans to improve fuel efficiency in transport through the wider use of cars with lean burn engines.

Mitigation of climate change requires action at all different levels from international to national and local levels. Currently, most mitigation efforts in the energy sector in Southeast Asia have focused on improving energy efficiency, developing renewable energy sources, and promoting urban mass transit systems. Cities play a crucial role in implementation of national standards. They have the capacity to issue building permits and ensure projects that meet energy regulations, and they can introduce new energy conservation rules in the plans. They also provide a platform to launch efforts to mitigate emissions which would not only result in the reductions of national emissions but also would bring benefits at local scale. In the near term, policy changes in Southeast Asian cities would be required to begin the shift of development patterns in a manner that moves toward low-carbon cities, and avoids some of the most adverse climate change impacts.

In addition to the supply and demand-side policies, the embodied energy policy due to consumption-based activity should be considered, since cities are a centre of consumption activity, particularly large cities. Instead of focusing on emissions produced within the city's border, many studies argue that a consumption-based responsibility would be more equitable as the necessary deep cuts in emissions, since it takes into account trade, emphasizes demand-side action, prevents carbon leakage, and provides a stronger rationale for low-carbon technology transfer and deployment in developing countries (Wang and Watson 2008). A consumption-based emissions account might also help the developing countries to negotiate in the post-2012 climate agreement as strategic emission reductions measure.

TABLE 1
Major Energy and Climate Policies in Selected Southeast Asian Countries

Case studies	Relevant policies at national and city levels	Key policy measures
Bangkok (Thailand)	The Energy Conservation Promotion Act (ENCON Act) – passed in 1992, is the primary legislation guiding Thailand's energy conservation and renewable energy policy.	- compulsory programmes - voluntary programmes - regulation - building code - labels - energy performance standards - financial incentive
	National Strategy on Climate Change – approved in 2008	- information - capacity building - research and development
	Strategic Plan for Renewable Energy Development – issued in 2003, aims to increase the share of renewable energy in the primary energy consumption to 8% in 2011	- renewable portfolio standard, 5% of new power plants must be generated by renewable energy - investment incentives - tax measures - net metering regulations - public-private partnerships - feed-in tariffs
	Bangkok Metropolitan Administration Action Plan on Global Warming Mitigation 2007 – 2012, set a target to reduce carbon emissions by 15% per year from 2007-2012	- information - voluntary programmes
Hanoi (Viet Nam)	National Energy Policy (2004) – providing electricity services in the rural areas and support an acceleration of renewable electricity production.	- foreign or local investment for off-grid supply
	National Energy Efficiency Programme 2006-2015 – approved in 2006, aims to reduce 3%-5% of total energy consumption by 2010, and 5%-8% reduction by 2015	- information - scientific and technological activities - voluntary labels

TABLE 1, *continued*

Case studies	Relevant policies at national and city levels	Key policy measures
Jakarta (Indonesia)	The Energy Law – promulgated in 2007, is ruled important institutional and legal changes on Indonesia's energy policy.	- financial subsidies - regulation - information and training - voluntary labels
	National Energy Policy – issued in 2004, sets a 5% target of renewable energy in power generation by 2020.	- power purchase programme for small-scale power generation - renewable energy targets - feed-in tariffs - voluntary corporate efforts
	National Action Plan for Climate Change	- guide for climate change mitigation and adaptation efforts
Manila (the Philippines)	Renewable Energy Policy Framework – issued in 2002, aims to reduce the country's dependence on imported energy, broaden resource base, and save foreign exchange and reduce emissions.	- renewable energy targets - regulating in geothermal, mini-hydro andwind - tax measures - public-private partnerships - voluntary corporate efforts
	Department of Energy Act – issued in 1992, an Act creating the department of energy rationalising the organisation and functions of government agencies related to energy and for other purposes.	- financial subsidies - tax incentives - regulation - energy performance standards - mandatory product labels

Sources: Pacudan 2005; APERC 2008; ADB 2009.

4. ENERGY USE AND CO_2 EMISSIONS IN SELECTED CITIES

4.1 Definition of the Case Studies

Data from disparate reports and studies can sometimes be incompatible because different definitions of a city are employed.. To remedy this problem, this paper uses the definition of a city based on local administrative definitions. Table 2 provides basic indicators of the case studies (Bangkok, Hanoi, Jakarta and Manila), while Table 3 shows the population estimates and projections.

TABLE 2
Basic Indicators of Case Studies

City	Population in 2005 ('000)	Economic Product in 2004 ($M)	Land Area (sq. km)	Population Density (people/sq.km)
Bangkok	5,483	63,088	1,569	3,495
Hanoi	3,183	NA	921	3,348
Jakarta	8,864	24,592	661	13,397
Metro Manila	10,677	32,277	636	17,453

NA – not available. *Source:* UN-HABITAT Database.

Bangkok is governed by the Bangkok Metropolitan Authority (BMA) with a total land area of 1,568 km^2. Bangkok consists of 50 districts and 154 sub-districts. It is the overwhelming centre of culture, population and economic development for Thailand.

Hanoi city lies in the centre of the Hanoi region on the bank of Red River. Hanoi is an administrative area consisting of nine urban districts and five suburban/rural districts. It has a land area of 921 km^2. Hanoi today is experiencing rapid economic growth and industrial expansion.

Jakarta is located in a low land area with average height around 7 m above sea level and comprised of 661 km^2. Jakarta is divided administratively into six municipalities. It is inhabited by variety of races and tribes, with different socio-cultural background both in terms of population size and economics.

Metro Manila is composed of four districts with twelve cities and five municipalities. It contributes 30% of the Philippines' GDP. Metro Manila also provides almost half of the total national output in manufacturing, commerce and services. Metro Manila accounts for about 13% of the country's total population.

TABLE 3
Population Estimates and Projections in Case Studies

Unit: (thousands)

City	2010	2020	2025
Bangkok	6,918	7,807	8,332
Hanoi	4,723	6,036	6,754
Jakarta	9,703	11,689	12,363
Manila	11,662	13,892	14,808

Source: UN 2007.

4.2 Comparison of Energy and Emissions

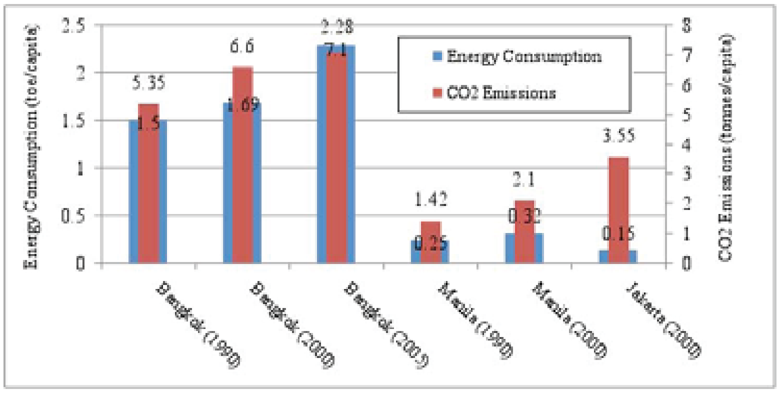
Cities offer major opportunities to reduce energy demand and to mitigate the impact of global climate change, just as they drive the economy of their nations. Cities that are not properly planned or managed can be a burden on natural resources and threaten quality of life. Cities and urban activities are usually blamed for global increases in GHG emissions, but UN-HABITAT (2008) analysis shows that the emissions from cities are more related to consumption patterns and income per capita (i.e. GDP/capita) rather than the urbanisation levels. When comparing cities' energy use and carbon emissions, it is important to discuss the complexities involved, not only the size of an economy, its transport, and household consumption pattern.

According to the Asian Development Bank study team (ADB 2009), the four countries emitted a total of 544 Mt of energy-related CO_2 emissions in 2000. They consumed a total of 193 Mtoe of primary energy, including 113 Mtoe of oil (58%), 47 Mtoe of natural gas (24%), 30 Mtoe of coal (16%), and the remaining 3 Mtoe (2%) from renewable energy.

In this study the emission performance of cities is measured in terms of CO_2 emissions per capita. Emissions per capita is a better indicator than emissions alone because it internalises some of the equity debates (Dhakal 2008). A comparison of energy and associated CO_2 emissions from Bangkok, Jakarta and Manila is shown in Figure 2.

A limitation of this study is a lack of sound data on urban energy consumption. Because disaggregated data is not available, it is not clear what proportion of the overall emissions is generated in urban areas, although since most buildings and transport networks are located in cities, urban areas are most likely responsible for a large proportion of these emissions (UN-HABITAT, 2008). It is important to understand which sectors consume the most energy to take appropriate actions for emission reductions.

FIGURE 2
Comparison of Energy and CO_2 Emissions from Selected Cities



Source: Ajero 2002; APN 2004; and BMA 2009.

4.3 Urban Transport

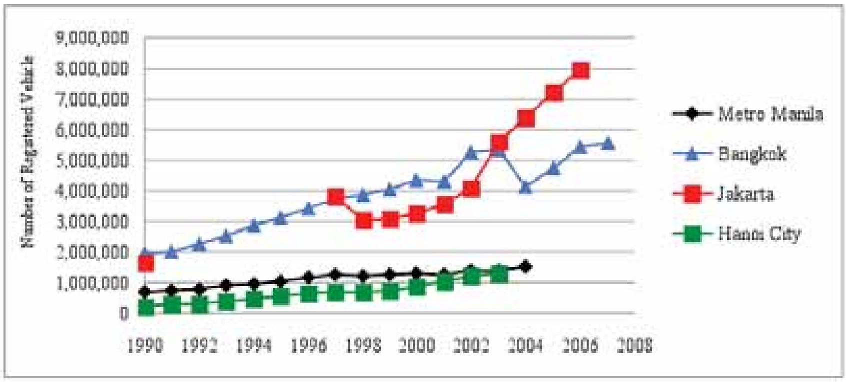
Transport sector is a major contributor of CO_2 emissions in the case studies. Rapid growth in urban population has contributed to high growth in demand for transport services and energy consumption. This sector also emits other pollutants such as NO_x, SO_2, CO, particulate matter, etc. into the atmosphere. These gases lead to worse air quality in urban areas. The four case studies have established plans to expand and introduce mass transit systems or to develop road infrastructure in order to alleviate congestion and improve the overall energy efficiency of urban transport.

Figure 3 shows trends in number of registered vehicles in the case studies. In Bangkok, Jakarta and Manila, the modal share of public transport varies between 40% and 60% of total person trips (Nhan 2008). By contrast, in Hanoi the percentages of individual private motorcycles and bicycle are extremely high, which accounts for 60% and 30%, respectively (Hoang, 2004). Table 4 presents the structure of current and estimated future energy demand in transport sector.

Bangkok has two mass rapid transit (MRT) systems: the Sky Train and Subway. Sky Train has 23 km of elevated track that transports about 400,000 passengers per day. The subway is an underground route of 20 km that transports around 20,000 passengers daily. BMA is extending the Sky Train in several phases with a total length of 7.5 km extension. Bangkok also plans to extend existing MRT lines, amounting to a total of 118 km by 2020. Moreover, Bangkok is developing a bus rapid transit system that is expected to carry 50,000 passengers daily.

Hanoi's transport is now characterised by motorcycles and rapid growth in passenger vehicle ownership. Buses account for a small portion of total personal

FIGURE 3
Number of Registered Vehicles in Case Studies



Source: Land Transport Office, the Philippines; Department of Land Transport, Thailand; Transport Development and Strategy Institute, Viet Nam; and Wirahadikusumah 2002.

trips. According to the master plan, Hanoi will develop a transport system that can accommodate the increasing number of passengers. Hanoi aims to increase the density of its urban road network.

Jakarta is dependent on road transport. Passenger vehicles account for about 11% of total personal trips, while buses account for 52% of total personal trips. According to a transport master plan, Jakarta aims to reduce its congestion problem and energy consumption as well as CO_2 emissions through investment in road infrastructure and the development of MRT systems.

Currently, Manila has three MRT systems in operation, including one MRT and two light rail transit (LRT) systems. Manila plans to expand the existing lines and further develop the LRT systems. As part of a plan to reduce congestion and manage transport efficiently, Manila plans to develop two rails that connect the city centre to suburban areas.

TABLE 4
Structure of Fuel Share and Estimated Energy Demand from the Urban Transport Sector

		Fuel Share (%)		
		Bangkok	**Jakarta**	**Manila**
2005	Gasoline	48.9	50.1	55.2
	Diesel	43.9	49.0	44.3
	LPG	6.1	NA	NA
	CNG	0.1	0.9	0.0
	Electricity	1.1	NA	0.5
	Total energy demand (10^6 GJ)	180.4	242.5	93.3
2020	Gasoline	56.9	48.0	48.4
	Diesel	38.9	51.1	51.4
	LPG	3.5	NA	NA
	CNG	0.1	0.9	0.1
	Electricity	0.7	NA	0.1
	Total energy demand (10^6 GJ)	347.6	571.7	598

LPG stands for Liquefied Petroleum Gas and CNG stands for Compressed Natural Gas.
NA — not available. *Source:* AIT 2002; and Phdungsilp 2006.

5. SUMMARY

Cities are not just victims of climate change but also part of the problem, which means they are also part of the solution. Cities in the developing world show different energy end-use distribution according to their size and stage of economic development. The case studies show that they are not only engines of their representative countries' economic growth, but also of the regional economies. Factors driving energy consumption and energy-related emissions in cities are interconnected in many respects. The challenges are to create knowledge based policies and to implement energy conservation and mitigation practices. Better scientific knowledge is a prerequisite for understanding the various causes of emissions and for implementing such measures.

Cities in Southeast Asian countries are continuing to grow due to changes in urban demographics, income level, lifestyle and related socio-economic development. This study shows that the projected population in Bangkok, Hanoi, Jakarta and Metro Manila will reach 7.76, 5.78, 20.77 and 13.4 million, respectively, by the year 2020. This will lead to intensive energy consumption in urban areas. In terms of per capita energy consumption and CO_2 emissions, Bangkok is the highest in the region. In terms of sectors, transportation is the largest energy consumer in these cities. Strategies to reduce transportation-related energy consumption and CO_2 emissions include modal shifts to mass transit, urban planning and public transport, and fuel economy standards. Many initiatives have been introduced and implemented to achieve co-benefits of reducing energy consumption and improving urban air quality.

The way cities are designed and managed over the coming decades will have a large influence on the future of the carbon cycle both locally and globally. Well-designed and well-managed cities provide many opportunities to reduce per capita energy consumption and/or carbon emissions. Carbon management would play an important role in the city's climate policy. A key need in these efforts is to develop a science-based policy and implementing framework for cities in which energy and climate mitigation measures are addressed in an integrated manner and to explore alternative development pathways for cities.

References

ADB (Asian Development Bank). 2008. *Managing Asian Cities: Sustainable and Inclusive Urban Solutions*. Manila, Philippines. www.adb.org.

______. 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review*. Manila, Philippines. www.adb.org.

AIT (Asian Institute of Technology), Thailand. 2002. *Energy, Environment and Climate Change Issues: A Comparative Study in Asia*. A study by the Asian Regional Research Programme in Energy, Environment and Climate – Phase II.

Ajero, M.Y. 2002. "Emissions Pattern of Metro Manila." Proceedings of IGES/APN Mega-City Project, Kitakyushu, Japan, January 23–25.

APERC (Asia Pacific Energy Research Centre). 2008. *APEC Energy Overview 2007*. Asia Pacific Energy Research Centre, The Institute of Energy Economics, Japan. www.ieej.or.jp/aperc/.

APN (Asia-Pacific Network for Global Change Research). 2004. I*ntegrating Carbon Management into Development Strategies of Cities – Establishing a Network of Case Studies of Urbanization in the Asia-Pacific*. Project 2004-07-CMY-Lasco.

Baumert, K.A., T. Herzog, and J. Pershing. 2005. *Navigating the numbers: Greenhouse gas data and international climate policy*. World Resource Institute, USA. http://pubs.wri.org_pdf.cfm?PubID=4093.

BMA (Bangkok Metropolitan Administration). 2009. *Bangkok Assessment Report on Climate Change 2009*. Bangkok, Thailand. www.roap.unep.org/pub/index.cfm.

Dhakal, S. 2004. *Urban Energy Use and Greenhouse Gas Emissions in Asian Mega-Cities: Policies for a Sustainable Future.* Kitakyushu, Japan: Urban Environmental Management Project, Institute for Global Environmental Strategies.

______. 2008. "Climate Change and Cities: The Making of a Climate Friendly Future." In *Urban Energy Transition – From Fossil Fuels to Renewable Power*, ed. Droege, P. Elsevier Publication.

Hoang, P.D. 2004. "Promoting Mass Transit for Improving Urban Environmental Management: A Focus on Pricing and Financing of Bus Service in Hanoi City, Vietnam." MSc. Thesis in Urban Environmental Management (UE-04-02), School of Environment, Resources and Development, Asian Institute of Technology, Thailand.

Nhan, L.T.T. 2008. "Developing Eco-efficiency Indicators for an Urban Transportation System in Hanoi City, Vietnam." MSc. thesis in Urban Environmental Management (UE-08-18), School of Environment, Resources and Development, Asian Institute of Technology, Thailand.

Pacudan, R. 2005. *Renewable Energy Policies in ASEAN: Background Paper. Information for the Commercialisation of Renewables in ASEAN*. Denmark: Risoe National Laboratory.

Phdungsilp, A. 2006. "Energy Analysis of Sustainable Mega-Cities." Licentiate of Engineering Thesis, Department of Energy Technology, Royal Institute of Technology, Stockholm, Sweden.

UN (United Nations). 2007. *World Urbanization Prospects: The 2007 Revision.* United Nations Department of Economic and Social Affairs/Population Division.

UNESCAP (United Nations Economic and Social Commission for Asia and the Pacific). 2008. *Statistical Yearbook for Asia and the Pacific 2008*. UNESCAP. www.unescap.org/stat/data/syb2008/.

UN-HABITAT (United Nations Human Settlements Programme). 2008. *State of the World's Cities 2008/2009: Harmonious Cities*. UK: Earthscan.

Wang, T., and J. Watson. 2008. "China's Carbon Emissions and International Trade: Implications for Post-2012 Policy." *Climate Policy* 8: 577–87.

Wirahadikusumah, K. 2002. "Jakarta Air Quality Management: Trends and Policies." The Regional Workshop on Better Air Quality in Asian and Pacific Rim Cities, Hong Kong, December 16.

PART 3

City Institutions and Governance for Climate Change

CHAPTER 16

Understanding and Improving Urban Responses to Climate Change

Reflections for an Operational Approach to Adaptation in Low and Middle-Income Countries

Roberto Sanchez Rodriguez*

Abstract

This article reflects on the construction of an operational approach for adaptation to climate change in low and middle-income countries. I depart from the assumption that climate change is a development challenge for urban areas and that adaptation to its impacts needs to be considered a learning process rather than a single product. I argue that an operational approach to climate change needs to address the formal and the informal process of urban growth in order to be efficient. This requires attention to the balance between structure and agency in the construction of the urban space and the combination of top-down and bottom-up actions. The article considers the role of urban institutions and the collaboration between scholars and local governments and stakeholders as part of an operational approach for adaptation.

*Corresponding author: roberto.sanchez-rodriguez@ucr.edu

1. INTRODUCTION

Urban responses to climate change have grown rapidly during the last decade in several parts of the world. However, many of these responses have focused solely on mitigating greenhouse gas emissions. Only a limited number of large urban areas have begun to consider adaptation as part of their response to climate change. Attention provided to mitigation over adaptation by international organizations, national and local governments, the mass media, and stakeholders has diverse causes (Schipper 2006; Moser and Satterthwaite 2007). But the Fourth Assessment of the IPCC (Wilbanks et al. 2007) has brought attention to the impacts of climate change and how societies can better adapt to them.

Particularly critical is the situation of urban areas in low and middle-income countries with severe development pressures and few resources and information to respond to the challenges of climate change. Connecting current urban development challenges with climate change is an effective tool for initiating adaptation in those societies. A critical step in this direction involves considering urban growth as more than just the outcome of local forces. This simplified perspective is common in urban planning and often leads to incomplete strategies seeking to address complex realities. It is also important to conceptualize climate change as more than an environmental problem; rather, it is fundamentally a development challenge for societies. Focusing on structural conditions of urban development and how they interact with climate change can be instrumental in helping societies define a better future. The size, form, structure, and function of urban areas and their future growth trajectories are critical elements to be considered in the discussion on climate change and the sustainability of societies.

Recent attention paid to adaptation and urban areas within the debate on climate change by the international community has begun to pay off. International and regional organizations (UN, The World Bank, OECD, etc.) have started to create programs supporting adaptation. International donors are starting to prioritize urban adaptation in low and middle-income countries. Scholars have begun to deepen their understanding of adaptation by addressing the diverse dimensions of this complex issue. Moreover, some urban areas have begun to create and implement adaptation strategies. These contributions have enhanced the visibility and relevance of climate change at the local level. However, parallel efforts fostering operational approaches to adaptation are urgently needed in order to meet the needs of local government and stakeholders. This discussion is timely given the rapid pace of urban growth in middle and low-income countries and the current difficulty of designing adaptation strategies in urban areas. Current urban policy decisions have the potential to either constrain or facilitate future urban adaptation strategies. Further delays in developing and implementing adaptation plans can have severe consequences for millions of urban inhabitants as well as local and national economies.

This article addresses challenges and opportunities for adaptation in urban areas of low and middle-income countries. It highlights the importance of connecting climate change adaptation to the fundamental drivers of both formal and informal urban growth. Focusing only on formal or informal urban growth creates incomplete perspectives that are likely to spark conflicts and contradictions among adaptation responses. Moreover, it is important to conceive of adaptation as a process involving the dynamic transformation of urban space over time. This article argues that adaptation strategies need to recognize those dynamics to maintain their effectiveness in the short and long-term. Ultimately, adaptation must be considered a learning process rather than a one-time product.

2. A PERSPECTIVE ON THE CHALLENGES AND OPPORTUNITIES FOR ADAPTATION

Adaptation involves taking actions to reduce harm and risk to an extreme event. It can also describe a society's evolution to a higher stage of social well-being. Adaptation provides an umbrella for the design and enforcement of actions intended to reduce vulnerability (Adger and Vincent 2005; Smit and Wandel 2006). It is perceived as a long-term process to decrease the vulnerability of local society. Adaptation does not have the same appeal as mitigation with respect to its benefits for the international common good, and as a result, is often less appealing to mass media, decision makers, and stakeholders. Moreover, uncertainty about the type, location, frequency, intensity, and extent of climate change impacts make adaptation strategies difficult to design (who should adapt to what and where?). There is also a perception among local elected officials, practitioners, and stakeholders that the impacts of climate change will occur sometime in the distant future and there is no need to invest in adaptation since scarce resources should be devoted to solving current urban and environmental problems.

A useful departure point for the discussion of climate change in urban areas is to consider urban areas as complex and dynamic systems where problems and contradictions within and among societies become evident in their daily operation and the type of urban space created (formal and informal urban growth). This viewpoint is useful for understanding why urban areas are burdened with many of the problems associated with growth, particularly in low and middle-income countries. Unemployment and underemployment, environmental degradation, deficiencies in urban services and housing, deterioration of existing infrastructure, problems in guaranteeing access to natural resources vital to urban life (water, energy, food, construction materials), and an expansion of violence and crime are some of the most visible problems common to urban areas (Moser and McIlwai 2006; Martine et al. 2007; UN-Habitat 2007). Those problems are aggravated by rapid population growth and the current economic, financial, and social crises unique to each country.

Climate change also has great potential to exacerbate these problems. Thomas and Twyman (2005) highlight the fact that climate change does not occur independently of other social processes. They call attention to how the interface between climate change and development processes can enhance existing inequalities. Adger et al. (2005) highlight the key role of underlying distributions of power within the institutions that manage resources and often create vulnerabilities to climate change. For them, present-day adaptation actions reinforce existing inequalities and do little to alleviate underlying vulnerabilities. They suggest that measures to reduce poverty and increase access to resources could reduce both future and present-day vulnerabilities and will ultimately facilitate adaptation to climate change.[1] However, adaptation at the local level may be limited by national and international regulations and pressures that determine the legal rights to resources, levels of resource out-take, availability of resources, and conflicts over the interpretation of regulation or limited enforcement of regulation (Keshitalo and Kulyosaba 2009). Societies with obstacles to democratic representation and efficient governance can also face obstacles for human agency and bottom-up initiatives for adaptation. It cannot be assumed that resources for adaptation are distributed on the basis of need, relative to exposure to stresses. Often times resource allocation is determined politically or economically, with the most powerful interest groups and decision makers granted a larger proportion of resources (Adger et al. 2005).

Despite these challenges, Martine et al. (2007) argues that urbanization can offer people a better chance to live fuller lives, help to unshackle the bonds of perennial poverty, and deflect environmental damage with the support of proper policies. Indeed, urban societies offer unique opportunities for development. There are clearly problems that need to be improved, particularly in urban areas of low and middle-income countries. But even urban societies with severe development pressures have encouraging examples of bottom-up projects improving livelihoods and communities in poor urban neighborhoods (Carolini 2007; Satterthwaite et al. 2007). Missing so far are initiatives connecting climate change (vulnerability and adaptation) with local efforts to improve urban growth, poverty reduction, sustainable livelihoods. An important step in this direction is

[1] It is interesting to note that a similar approach is suggested to help biodiversity adapt to climate change. Lawler (2009) suggests the removal of non-climatic treats to a species or systems and reducing other stresses on species as the most obvious approaches to increase resilience to climate change. Burton (1997), Adger et al. (2005), Thomas and Twyman (2005), Smit and Wandel (2006), Satterthwaite et al. (2007) and others scholars suggest a similar principle of adaptation, protecting individuals and communities through poverty and social inequity reduction, improving livelihoods, and strengthening governance.

connecting current development challenges in urban areas with the design and implementation of climate change adaptation strategies. Dovers (2009) highlights the importance of connecting adaptation more closely to existing policy and management understanding in communities, professions, and agencies, and to the existing agendas, knowledge base, and risks they already face. He suggests that, in at least some relevant sectors, there is an existing set of reasoned options on which to base adaptation policy development, representing a better beginning than starting afresh. This approach has been suggested by other scholars (Burton 1997; Beg et al. 2002; Shipper 2006; Smit and Wandel 2006) and is highly relevant for fostering the participation of local elected officials, practitioners, and stakeholders in building and implementing adaptation strategies. Equally important are parallel efforts to connect informal urban growth and community development initiatives with adaptation. I will discuss this point later on in this chapter.

A point of clarification is in order in this discussion. Mainstreaming adaptation strategies in urban policies can be achieved through formal mechanisms often found in urban planning (building codes, land use permits, etc.) and through economic incentives common in the formal regulation of the build environment in many urban areas. But it would be unwise to neglect informal urban growth in many low-income and middle-income countries. Those communities grow rapidly, they represent a large extent of the urban area, and they are among the communities with the highest vulnerability and most urgent need to adapt to climate change (Martine et al. 2007; Satterthwaite et al. 2007; Wilbanks and Romero-Lankao 2007; UN-Habitat 2007).

The introduction of this article highlighted the importance of connecting adaptation to climate change with the driving processes of formal and informal urban growth in low and middle income-countries. Attention so far has focused on formal urban growth within the framework of urban planning. But initial to connect pro-poor programs with climate change have begun to appear in informal settlements. Ideally, adaptation strategies need to be imbedded within urban growth trends and urban development strategies. Focusing only on formal or informal urban growth will leave half of the problem unaddressed. Therefore, there are two issues that need to be considered with respect to adaptation. First, adaptation needs to be considered a process rather than a single product. Indeed, adaptation strategies need to be updated and improved periodically in order to incorporate changes in climatic, socioeconomic, and urban conditions. Adaptation as a learning process can create a framework that facilitates the development of multidimensional perspectives of urban growth and creates synergies with efforts towards sustainable development. Second, this process must recognize the critical balance between structure and agency in urban growth.

3. STRUCTURE AND AGENCY

The promotion of adaptation opportunities, and the subsequent reduction of social and urban vulnerability, depend on balancing the policies and actions of socioeconomic and political systems with human agency. Structural socioeconomic constraints are often addressed by top-down approaches and their implementation and effectiveness depend on complex politically negotiated processes. The construction of urban infrastructure, housing programs, and urban services are top-down actions managed by the formal framework of state control (urban planning) and the real estate market. It would be unrealistic, however, to expect that those processes could make a difference by themselves, particularly in urban areas of low and middle-income countries. This is because a significant part of the rapid urban growth in this context takes place outside of the formal framework of urban planning and top-down approaches do not reach those areas often. Top-down actions are not necessarily responsive to low-income individuals and groups, neglecting their needs and the value of agency (Hull 1998; Watson 2009). Therefore, bottom-up initiatives are extremely important for the design of actions to reduce vulnerability and provide opportunities for adaptation in those communities. Combining bottom-up and top-down approaches in policies and strategies that reduce social vulnerability will create more balanced and integrated adaptation responses to climate change in low and middle-income countries.

3.1 Formal Urban Growth

Mainstreaming climate change adaptation strategies with both urban development policies and informal urban growth can have benefits in the short and long-term. An entry point where those benefits could reach many urban inhabitants is in the design and planning of the built environment (urban infrastructure, services, land use, and buildings). The life spans of buildings and infrastructure are often over 75 years and structures being built now will likely operate under different climatic conditions in the next decades. Current designs and investments seldom take into account the potential impacts of climate change that can cause significant dysfunctions in their operation. Taking into consideration scenarios of future extremes in temperature and precipitation would help progressive adaptation in the design of the built environment. Adjusting to current planning practices (building codes, infrastructure standards, land use regulations), and the regulatory and financial framework of formal urban growth are important steps in this direction. These actions can be achieved by selecting "no-regrets" strategies that yield benefits even in the absence of climate change. This can include initiatives such as flexible strategies and buying safety margins for new investments (Hallegatte 2009). This approach is particularly useful in light of the uncertainty associated with identifying climate change impacts at the urban level.

The study of social and urban vulnerability to climate change creates an analytical framework that is useful to the study of adaptation. The in-depth analysis of the driving forces of vulnerability considers social processes that condition the exposure of communities to extreme climatic events as well as their capacity to cope with those events (Adger 1999; Turner et al. 2003; Adger 2006). The same processes are also partly responsible for current socioeconomic, environmental, and urban problems that local elected officials, practitioners, and stakeholders can relate to. The study of vulnerability is also helpful for identifying who needs to adapt to what within the context of climate change and is an effective tool for helping local decision makers conceptualize how short-term actions can have long-term benefits. The concept of vulnerability is also an effective way to broaden the scope of policy and actions oriented to urban growth (biophysical and socioeconomic processes at the regional and global level). Several vulnerability scholars have drawn attention to factors influencing individuals' or groups' capacity to anticipate, cope, resist, and recover from the impact of a natural hazard associated with climate variability and climate change (Adger 1999; Mirza 2003; Pelling 2003; Moser and Satterthuaite 2008). However, it is also a useful approach in the design of adaptation strategies that can also be expanded to address climate change impacts beyond natural hazards (for example, impacts on health, the urban economy, social interactions within the urban area, ecological services, biodiversity and habitat conservation, etc.).

Case studies in Cartagena and Manizales Colombia are useful examples of the connection between urban vulnerability and adaptation to climate change in low and middle-income countries. Other studies on the potential impacts of sea level rise on coastal urban communities have created useful precedents for reducing social and urban vulnerability while simultaneously enhancing local adaptation to climate change (McGranahan et al. 2007; Scherbinin et al. 2007).

Information on future climate scenarios, and alternatives to progressively adapt to them, are also useful planning tools for reducing vulnerability and leveraging adaptation. Access to scientific information is often difficult for local official, urban planners, and stakeholders. Building collaboration with local, national, and regional universities can help bridge the gap between science and policy/practice. It can help incorporate the global and regional dimension of climate variability and climate change to adaptation in formal urban growth. I will return to this important issue later on. However, it is important to highlight that climate information becomes a useful tool for urban communities when it is imbedded in multidimensional adaptation strategies connecting current local urban, social, and environmental problems with climate change. Those strategies can help communities make an efficient use of scarce financial, technical, human, and natural resources, particularly in poor countries and emerging economies.

Development challenges in urban areas are often associated with financial constraints for building urban infrastructure and services, housing, and environmental protection, particularly in small and medium size urban areas in poor countries. Often times, the level of financing required is beyond the capability of most urban areas to provide and requires the participation of national/sub-national governments, and sometimes international funding agencies. The challenge of adaptation is not only a financing problem, however. Finding funding sources for urban growth in low and middle-income countries has always been a challenge. Making adaptation an integral component of that process has the potential to improve opportunities to secure funding. This is due in part to the fact that international and local attention to climate change has enhanced the pool of financial resources available to local governments to address development pressures in urban growth.

Stren's (2008) review of the international assistance for cities in low and middle-income countries outlines obstacles and opportunities of urban areas in the South. He suggests four ways in which urban assistance programs can be more effective. 1) Support research on local problems. For him, the development of South perspectives and approaches for urban development are essential, together with solidifying local knowledge about cities and enhance informed discussion of important issues. 2) Support South-South networks to better understand possible futures and scenarios to deal with their most challenging problems. 3) Continue to focus on pro-poor policies that enhance the opportunities for social change. 4) Act as responsible stakeholders, develop transparent and accountable assistance, and maintain local programs until there is general agreement they should be discontinued. These four strategies are also a useful model for developing and supporting adaptation programs in low and middle-income countries.

In the South, the role of international assistance has been central to the development of urban adaptation strategies. Roberts (2008) describes the city of Durban's experience (South Africa) and the process the municipality went through to create its adaptation plan. She illustrates the role of international assistance at different stages of the process. The cities of Cartagena and San Andres de Tumaco in Colombia assessed their urban and social vulnerability to sea level rise and climate change with the support of the Netherlands Climate Assistance Program. Their studies also included potential adaptation actions (http://www.nlcap.net/countries/colombia/). International assistance fostered the collaboration of local universities with local governments in South Africa and Colombia. These collaborations were key in building adaptation to climate change. Moreover, the partnership has been an important support for the sustainability of those plans.

The experience of political and administrative decentralization from national to local governments is also relevant to this discussion of multilevel funding of urban growth and adaptation to climate change. Decentralization has been considered a central driver of development opportunities for municipalities since the 1980s. The experiences of these processes are helpful in the discussion of adaptation to climate change in urban areas and the role of multi level governmental interactions in that process. A key experience of the decentralization efforts in Latin America and Africa is the importance of maintaining a balance between political and administrative decentralization (Ribot and Larson 2004). This includes transferring adequate resources to meet the new responsibilities at the local level and politically empowering the municipality in the decision making process. A second important lesson is that the national government should monitor the evolution of decentralization processes to avoid the cooption of benefits by power groups at the local level.

Other experiences from relevant urban development projects in these countries have taught us two important lessons: the importance of multidimensional and integrated approaches of urban development to reduce unintended negative consequences from the projects (social, economic, environmental, and cultural impacts); the critical role of combined top-down approaches addressing structural socioeconomic conditions with bottom-up approaches facilitating human agency, the use of local knowledge, and the sustainability of the project. Many bottom-up projects are based on low-cost solutions that involve alternative technologies and ecosystem services. They provide useful alternatives for adapting to climate variability and climate change.

3.2 Informal Growth

The creation of the urban space in low and middle-income countries is characterized by the rapid growth of informal settlements and their incorporation over time into the real estate market and to the formal part of the city. Informal growth results from complex social processes, the limited capacity of local and national governments to meet the demand of housing and urban services, and human agency. Countries in Latin America, Africa, and Asia have diverse experiences addressing the challenges of informal urban growth, but a commonly found feature is the location of settlements in hazardous areas that are at high risk to the impacts of climatic events.

There is a large literature on informal urban growth. I will limit my remarks to suggest how adaptation strategies to climate change can address informal settlements in urban areas. Moser and Satterthwaite (2008) propose a pro-poor adaptation approach for urban areas in low and middle-income countries. They assert that addressing the social development dimensions of climate change adaptation in urban areas requires considering the roles of not only different levels of government but also individuals, households, and civil society organizations. They suggest a framework of pro-poor asset adaptation for climate change as a conceptual and operational framework. The framework helps identify the vulnerabilities of low-income individuals, households and communities to climate change and considers how their assets can support local adaptation. Although the framework can support a broader analysis of vulnerability, the authors focus on vulnerability and natural hazards, particularly in terms of protection to extreme events and post-disaster responses and rebuilding. Within this context, they suggest four sets of actions for adaptation: adjusting local planning regulatory and financial frameworks; bottom-up pressures for risk reduction; adjustment of current practices (building codes, land regulations, land use management); and factoring climate change related risks into new development plans and investment programs. The pro-poor asset adaptation framework is an encouraging effort to address informal urban growth in adaptation strategies. Using assets to connect urban and social vulnerability to climate change adaptation strategies can become a useful operational tool.[2]

The framework of assets, livelihoods, and social policy proposed by Anis and Moser (2008) is also useful. Originally, it was not developed to address adaptation to climate change but was conceptualized as a polycentric framework for social and economic development. It seeks to enable policy makers to recognize the different interests and claims on assets, and the roles and responsibilities of different social and institutional actors, if such assets are to be accumulated in an equitable and sustainable manner. The framework is part of efforts to eradicate poverty, fill productive employment, and enhance social integration. However, it combines key elements to reduce social and urban vulnerability and to foster climate change adaptation. It provides a multi-scale approach (polycentric) to development that is responsive to both national needs and transnational processes. Moreover, it combines a holistic approach to assets with sustainable livelihoods.

Moser (2008) proposes a second-generation asset-based policy as an effort to sustain current poverty reduction policies focusing on the provision of housing, urban services and infrastructure, health, education and microfinance. She argues that the benefits of first generation efforts in terms of assets accumulation can been eroded by the globalizing institutional context and that their effectiveness to reduce poverty and social inequality can be lost over time. The second-generation asset-based policy is designed to strengthen accumulated assets and to ensure their further consolidation. This approach can be partic-

[2]See also the work of Adger (1999) in Vietnam for the use of entitlement theory in the study of vulnerability to climate change.

ularly useful in addressing adaptation to climate change as a process. Current attention to reducing social and urban vulnerability and to adaptation is closely connected to poverty reduction efforts mentioned above (provision of housing, urban infrastructure and services, etc.). Strengthening poverty reduction efforts through asset-based policy and sustainable livelihoods can achieve structural transformations with multiple benefits: it can enhance opportunities for social change, reduce social and urban vulnerability, and enhance adaptation to climate change within the context of urban development. Moser's emphasis on strengthening accumulated assets is relevant to the process of urban growth in low and middle-income countries where informal settlements are progressively incorporated to the formal process of urban growth. Accumulated assets can be lost in the process of incorporating informal settlements into the formal structure of the urban area and the real estate market. The loss of accumulated benefits would also affect the reduction of vulnerability and the acceptance of adaptation strategies among poor inhabitants.

Moser and Anis' framework further facilitates the identification of actors and agents who need to be mobilized in efforts towards enhancing access to assets and sustainable livelihoods. They assert that assets create agency and provide support for bottom-up community asset-building. As I mentioned above, agency and bottom-up community-based asset building are relevant elements of adaptation strategies to climate change. Incorporating them into operational approaches for adaptation is necessary to assist urban areas build short and long-term sustainability. It is also important to maintain a comprehensive perspective of the interactions between structure and agency that will help retain a balance between top-down and bottom-up adaptation actions.

4. THE ROLE OF INSTITUTIONS

The discussion above leads us to consider the important role of institutions in the process of adaptation. International attention to climate change has begun to address the role of institutions (structures and operations) to meet global and regional challenges of the 21st century (O'Riordan and Jordan 1999; Biermann and Bauer 2004). Unfortunately, few substantial institutional changes have been achieved so far at the local, national, and international level, including those changes needed to meet the challenges of climate change. In the case of urban areas, a key question is the role of urban planning. Do planning institutions have the vision, capacity, and flexibility to update themselves and to guide future urban growth in order to meet the challenges of the 21st century? This is a relevant question because institutions, particularly public institutions, are reticent to change their operations and their structures. Public institutions are seldom self critical about their limitations and the steps needed to update and improve themselves. The situation is common among planning institutions, particularly in low and middle-income countries (Watson 2009). Such institutions are confronted by limited human, technical, and economic resources, and very limited capacity for research to create multidimensional perspectives of their urban problems. Urban planners are also prone to suffering limited support from mayors and local elected officials for mediation in the political negotiations among divergent interests of social groups in the urban space.

Urban planning is considered a societal tool to create order among activities in the urban space, to reduce conflicts among them, and to seek the well-being of their inhabitants (Blair 1973). This model has prevailed since the early schemes of urban planning more than a century ago. However, a number of scholars have pointed out the limitations of that model, including its difficulty in ordering complex urban systems. Blair (1973) highlighted thirty-five years ago the lack of capacity of urban planning to solve conflicts among economic, political, and socio-cultural priorities in the urban space. He stressed its mainly physical focus (the built environment). Blair called this approach the "poverty of urban planning." He criticized the techno-bureaucratic approach of urban planning that addresses problems ad hoc, with little scientific knowledge, without self-critique or a synoptic view of the problems. Moreover, Blair argues that the planning profession operates without updating its methodological and conceptual frameworks in order to meet the continuous changes in urban society. Blair proposes an alternative approach to urban planning based on multi-dimensional and interdisciplinary perspectives. It is worth noting the similarities between Blair's multi-dimensional proposal for urban planning 35 years ago and the need for multi-dimensional perspectives in addressing vulnerability and adaptation mentioned above.[3] Urban areas need to create new multidimensional and multi-scale approaches to orient their growth in the 21st century.

Non-governmental-organizations (NGOs) and community-base-organizations (CBOs) are also important urban institutions in many low and middle-income countries. Those organizations often supplement the limitations of local governments in the supply of urban services and play a key role in the design and implementation of bottom-up development projects (Carolini 2007). They can be also important actors in reducing social vulnerability and building adaptation responses to climate variability and climate change (Satterthwaite et al. 2007).

[3]By the same token, Simmie (1993) criticizes the techno-administrative function of urban planning incapable of controlling and orienting urban growth and the undesired consequences of concentrating the benefits of planning in some social groups and its negative costs on others. Hogan (2003) highlights the failure of urban plans in the U.S. despite more than a century of progressive urban planning. Bridge (2007) questions the assumption that urban planning would impose order to the inherent chaos of the city. He criticizes the dominant assumption within urban planning that the city can be directed by an instrumental rationality.

However, in the context of climate change, the work of these organizations can be strengthened by the appropriate linking of local experience and scientific knowledge (Blanco 2006).

Other urban institutions (i.e. professional associations of engineers, physicians, teachers) and economic institutions (Chambers of Commerce and other business organizations) are also active in local urban areas and can play a role in developing strategies to reduce vulnerability and enhance implement adaptation. Expanding their participation in the urban planning process and in the design of adaptation strategies can strengthen social commitment to those initiatives, supplement local knowledge, and expand community involvement in short and long-term strategies. Such institutions can become important actors in the social learning process of adapting to climate change.

5. THE COLLABORATIONS BETWEEN SCIENCE AND POLICY/PRACTICE

Despite the mentioned limitations of urban planning, the discipline represents a useful resource for adaptation. There is an extended presence of urban institutions in a large number of urban areas that can become important actors in adaptation to climate change. Offices of urban planning and public works exist in almost every local urban government and they are institutions with knowledge of local development pressures. Improving those institutions would be an important but a long-term project, particularly in poor countries and emerging economies (Verna 2007). A positive step in that direction is building collaboration between planning institutions and local, national, and regional research institutions with knowledge and experience on urban issues and climate change. This approach has helped cities like London, New York, Chicago, Seattle, Mexico City, Toronto, Cap Town, Durban, Manizales, and other cities in Europe, Africa, the Americas and Australia in the design of strategies and actions for mitigation and adaptation to climate change.

Lessons from collaborations between scientists and practitioners stress the importance of the following steps. First, it must be recognized that transferring scientific knowledge to local urban practitioners and decision-makers is difficult and alone, is not enough to build better responses to local urban problems and climate change. Rather, new useful knowledge can be constructed by valuing scientific contributions as well as those from the domain of practice (urban planners, decision-makers and stakeholders). The creation of a common space for knowledge sharing will facilitate the creation of useful knowledge (Roux et al. 2006; Turnholt et al. 2007). Second, the creation of a relationship among those actors should be based on trust and respect among participants, to build understanding and collaboration among them. Third, leadership is critical building multidimensional and transdisciplinary approaches to urban planning and adaptation to climate change. Leadership can come from any of those actors and it should provide a multidimensional vision of the urban system and its interactions with climate change.

The collaboration between scientists and planners, policy makers, and urban stakeholders can yield contributions in two critical areas: in the assessment of urban and social vulnerability to climate change risks and impacts, and in the development of multidimensional and multi-scale perspectives of the urban system where adaptation to climate change is linked to current urban growth trends and problems. Universities and research institutions can be instrumental in identifying cumulative impacts and risks from climate change in urban areas. Urban planners, decision makers, and stakeholders can develop a different perspective of their urban areas if the potential impacts of climate change are taken into consideration. The impact of sea level rise, seasonal and extreme variations in precipitation and temperature, their consequences for health, the urban structure and functions, together with the risk of natural hazards (flooding, drought, landslides, heat waves, wind storms, fires), can become strong incentives to identify how urban areas can better adapt to those changing conditions.

An additional opportunity for bringing climate change to the attention of local urban planners and officials is through the collaboration of international and regional organizations and the scientific community. International organizations (UNDP, UNEP, UN Habitat, World Bank, Metropolis, International Union of Local Governments, and other regional organizations) have capacity building programs designed to train public officials responsible for urban environmental planning and public works every year in poor countries and emerging economies. Those programs are often carried out in coordination with national governments. Adaptation to climate change has not yet been incorporated as part of the capacity building curriculum. However, the UN and other international organizations have begun to pay attention to the potential multiplying benefit if local officials relate their current development pressures with adaptation responses to climate change. These programs can have significant benefits on the short-term if they are carried out in coordination with local, national, and regional universities and research institutions to incorporate climate change into perspectives of urban growth. They can also assist in the creation of long-term partnerships between local and national universities and local decision-makers, planers, and stakeholders.

The role of NGOs and CBOs in urban development mentioned above is also relevant to the discussion of successful collaboration among urban institutions. Some NGOs and CBOs have research capacities adequate enough to incorporate the dimension of climate change as part of their activities. However, the majority of these institutions cannot carry out extensive research. Building collaboration among universities and research institutions, urban planners, and NGOs, CBOs, can strengthen climate adaptation strategies in both formal and informal settlements. This combined approached mentioned above represents the best alternative to address a large percentage of the built environment in many urban areas of low and middle-income countries. This issue is often neglected in the discussion of adaptation, but it is one that requires significant attention by efforts seeking to reach the majority of present and future urban inhabitants. Collaboration can be particularly useful for identifying hazardous areas, or places that are at risk to extreme climatic events. It can also illuminate components that contribute to the reduction of social and urban vulnerability, health consequences of climate change, the use of low cost technology, and the importance of ecosystem services.

6. CONCLUSIONS

This article contributes to the debate on operational approaches to climate change adaptation in low and middle-income countries. The article stresses the need to situate the debate within the context of the structures and agencies that define the construction of urban space. This approach is essential to addressing formal and informal urban growth and highlights the need to include top-down and bottom-up strategies as part of urban adaptation efforts. The explicit connection of social and urban vulnerability, sustainable livelihoods, and adaptation through an asset-based framework contributes to the creation of an integrated, multi-scale, and multidimensional vision of the urban area in which stakeholders and decision-makers can relate to their daily life and areas of concern. Such efforts will require taking advantage of the accumulated knowledge under diverse disciplinary studies and the promotion of transdisciplinary knowledge.[4] This approach is needed for the study of vulnerability and adaptation to climate change, and ultimately for operational strategies of sustainable urban development.

It is worth stressing the differences among adaptation strategies in urban areas of high and middle and low-income countries. Although urban areas in those countries share common development challenges (including climate change), they are significantly different in terms of their resources, needs, and values associated with addressing those challenges. Recognizing these fundamental differences is relevant to the design of adaptation strategies as well as to their implementation. Adaptation is site specific and its strategies must reflect local

[4]Breaking with the disciplinary culture of excessive specialization in favor of schemes that include interdisciplinary and trans-disciplinary thinking is not easy and requires time. But there is growing recognition of the need to complement the disciplinary vision with integrated multidimensional perspectives in the study of complex problems societies face in the 21st century (Giri, 2002; Ramadier 2004; Petts et al. 2006).

resources, needs, and values. Experiences from other urban areas are useful precedents that can contribute to more efficient learning processes of adaptation. But care should be given to how those experiences and knowledge are applied locally, particularly in the context of North-South collaboration.

Adaptation responses in urban areas have the potential to benefit large sections of society in low, middle, and high-income countries alike. Adaptation strategies in urban areas offer the opportunity to reach large parts of current and future global population. Moreover, multidimensional strategies that combine top-down and bottom-up approaches could integrate adaptation within formal and informal urban growth processes with short and long-term benefits that inhabitants, stakeholders, and local officials can relate to.

Finally, it is worth stressing the urgency of developing robust climate change adaptation strategies in urban areas. What it is been built now will likely operate in the future under different climatic conditions from those of today. Further delays in incorporating climate change into urban growth planning can reduce their functionality and aggravate the negative consequences of climate change. Efforts in the direction of adaptation have the potential to make a difference in the livelihoods of millions of present and future urban inhabitants.

References

Adger, N. 1999. "Social Vulnerability to Climate Change and Extremes in Coastal Vietnam." *World Development* 27 (2): 249–69.

______. 2006. "Vulnerability." *Global Environmental Change* 16 : 268–81.

Adger, N., N. Arnell, and E. Tompkins. 2005. "Successful Adaptation to Climate Change across Scales." *Global Environmental Change* 15: 77–86.

Adger, N. and K. Vincent. 2005. "Uncertainty in Adaptive Capacity." *Computers Rendus Geoscience* 337: 399–410.

Anis, A., and Moser C. 2008. "Asset-based Social Policy and Public Action in a Polycentric World." In *Assets, Livelihoods, and Social Policy,* ed. Moser C. and Dani A., 3-42. Washington, DC: The World Bank.

Beg, N. et. al. 2002. "Linkages between Climate Change and Sustainable Development." *Climate Policy* 2: 129–44.

Biermann, F. and Bauer S. 2004. "Assessing the Effectiveness of Intergovernmental Organizations in International Environmental Politics." *Global Environmental Change* 14: 189–93.

Blair, T. 1973 *The Poverty of Planning*. London: Macdonald Publishers.

Blanco, A. 2007. "Local Initiatives and Adaptation to Climate Change." *Disasters* 30 (1): 140–7.

Bridge, G. 2007. "City Senses: On the Radical Possibilities of Pragmatism in Geography." *Geoforum* 2007, doi: 10.1016/j.geoforum. 2007.02.004.

Burton, I. 1997. "Vulnerability and Adaptive Response in the Context of Climate and

Climate Change." *Climatic Change* 36: 185–96.

Carolini, G. 2007. "Organizations of the Urban Poor and Equitable Urban Development: Process and Product." In *The New Global Frontier. Urbanization, Poverty and Environment in the 21st Century,* ed. Martine G., McGranahan G., Montgomery M., and Fernandez-Castilla, R., 133–50. London: Earthscan.

Dovers, S. 2009. "Normalizing Adaptation. Editorial." *Global Environmental Change* 19: 4–6.

Giri, A. 2002. "The Calling of a Creative Transdisciplinarity." *Futures* 34: 103–15.

Hallegatte, S. 2009. "Strategies to Adapt to an Uncertain Future." *Global Environmental Change,* doi:10.1016/j.gloenvcha.2008.12.003.

Hogan, R. 2003. *The Failure of Planning*. Columbus, Ohio: State University Press.

Hull, A. 1998. "The Development Plan as a Vehicle to Unlock Development Potential?" *Cities* 15 (5): 327–35.

Keshitalo, C., and Kulyosava A. 2009. "The Role of Governance in Community Adaptation to Climate Change." *Polar Research* 28: 60–70.

Lawler, J. 2009. "Climate Change Adaptation Strategies for Resource Management and Conservation Planning." The Year in Ecology and Conservation Biology: Ann. N.Y. Acad. Sci. 1162: 79–98. doi: 10.1111/j.1749-6632.2009.04147.x C _ 2009. New York Academy of Sciences.

Martine G., McGranahan G., Montgomery M., and Fernandez-Castilla R. 2007. "Introduction." In *the New Global Frontier. Urbanization, Poverty and Environment in the 21st Century,* ed. Martine G., McGranahan G., Montgomery M., and Fernandez-Castilla, R., 1–16. London: Earthscan.

Mc Granahan, G., Balk D., and Anderson B. 2007. "Risk of Climate Change for Urban Settlements in Low Elevation Coastal Areas." In *the New Global Frontier. Urbanization, Poverty and Environment in the 21st Century,* ed. Martine G., McGranahan G., Montgomery M., and Fernandez-Castilla, R., 77–98. London: Earthscan.

Mirza, M. 2003. "Climate Change and Extreme Weather Events: Can Developing Countries Adapt?" *Climate Policy* 3: 233–48.

Moser, C. 2008. "Assets and Livelihoods: A Framework for Asset-Based Social Policy." In *Assets, Livelihoods, and Social Policy.* ed. C. Moser and A. Dani, 44–84. The Washington, DC: World Bank.

Moser, C. and McIlwaine, C. 2006. "Latin American Urban Violence as a Development Concern: Towards a Framework for Violence Reduction." *World Development* 34 (1): 89–112.

Moser, C., and Satterthwaite D. 2008. "Towards Pro-Poor Adaptation to Climate Change in the Urban Centers of Low and Middle-Income Countries." Human Settlements Discussion Paper: Climate Change and Cities 3, IIED, London.

Myllyla, S., and Kuvaja K. 2005. "Societal Premises for Sustainable Development in Large Southern Cities." *Global Environmental Change* 15: 224–37.

O'Riordan, I. and Jordan, A. 1999. "Institutions, Climate Change and Cultural Theory: Towards A Common Analytical Framework," *Global Environmental Change* 9: 81–93.

Pelling, M. 2003. *The Vulnerability of Cities. Natural Disasters and Social Resilience.* London: Earthscan.

Petts, J., Owens S. and Bulkeley H. 2006. "Crossing Boundaries: Interdisciplinarity in the Context of Urban Environments." *Geoforum* doi:10.1016/j.geoforum.2006.02.008.

Ramadier, T. 2004. "Transdisciplinarity and its Challenges: the Case of Urban Studies." *Futures* 36: 423–39.

Roberts. D. 2008. "Thinking Globally, Action Locally: Institutionalizing Climate Change at the Local Government Level in Durban, South Africa." *Environment and Urbanization* 20 (2): 521–37.

Roux, D., Roggers K., Biggs H., Ashton P., and Sergeant A. 2006. "Bridging the Science-Management Divide: Moving from Unidirectional Knowledge Transfer to Knowledge Interfacing and Sharing." *Ecology and Society* 11 (1). http://www.ecologyandsociety.org/vol11/iss1/art4/.

Satterthwaite, D., Saleemul H., Pelling M., Reid H., Lankau-Romero P., 2007. "Adapting to Climate Change in Urban Areas: Possibilities and Constraints in Low-And-Middle-Income Nations." Human Settlements Discussion Paper: Climate Change and Cities 1, IIED, London.

Scherbinin, A., Schiller A., and Pulshiper A. 2007. "The Vulnerability of Cities to Climate Hazards." Environment and Urbanization 19 (1): 39–64.

Schipper, L. 2006. "Conceptual History Of Adaptation in the UNFCCC Process." Reciel 15 (1): 82–92.

Simmie, J. 2003. *Planning at the Crossroads*. London: University College London.

Smit, B., Wandel, J. 2006. "Adaptation, Adaptive Capacity and Vulnerability." Global *Environmental Change* 16: 282–92.

Stren, R. 2008. "International Assistance for Cities in Low and Middle-Income Countries." *Environment and Urbanization* 20 (2): 377–93.

Thomas, D., and Twyman, C. 2005. "Equity and Justice in Climate Change Adaptation amongst Natural-Resources-Dependent Societies." *Global Environmental Change* 15: 115–24.

Turner II, B.L., Kasperson R., Matson P. McCarthy J., Corell R., Christensen L., Eckley N., Kasperson J., Luers A., Martello M., Polsky C., Pulsipher A., and Schiller A. 2003. "A Framework for Vulnerability Analysis in Sustainable Science." *Proceedings of the National Academy of Sciences of the United States of America* 100 (14): 8074–79.

Turnhout, E., Hisschemoeller M., and Eijsackers H. 2007. "Ecological Indicators: Between the Tow Fires of Science and Policy." *Ecological Indicators* **7**: 215–28.

UN-Habitat (United Nations Human Settlement Programme). 2007. *Enhancing Urban Safety and Security; Global Report on Human Settlements 2007*, 480. London: Earthscan.

UNFP (United Nations Population Fund). 2007. *State of the World Population 2007. Unleashing the Potential of Urban Growth.* New York: United Nations.

Verna, N. 2007. *Institutions and Planning*. Bingley, Emerald.

Watson, V. 2009. "The Planned City Sweeps the Poor Away: Urban Planning and 21st Century Urbanization." *Progress in Planning* 72: 151–93.

Wilbanks, Tom, and Patricia Romero Lankao with Manzhu Bao, Frans Berkhout, Sandy Cairncross, Jean-Paul Ceron, Manmohan Kapshe, Robert Muir-Wood and Ricardo Zapata-Marti. 2007. "Industry, Settlement and Society." In *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of WorkingGroup II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. Martin Parry, Osvaldo Canziani, Jean Palutikof, Paul van der Linden and Clair Hanson, 357–90. Cambridge University Press, Cambridge and New York.

CHAPTER 17

Planning Climate Resilient Cities: Early Lessons from Early Adapters

JoAnn Carmin,* Debra Roberts, Isabelle Anguelovski

Abstract

Climate change is expected to place increasing stress on the built and natural environments of cities as well as create new challenges for the provision of urban services and management systems. Minimizing the impacts of climate change requires that cities develop and implement adaptation plans. Despite the imperative, only a small number of cities have initiated the adaptation planning process. Drawing on theories of diffusion and capacity, and empirical assessments of initiatives in Durban, South Africa and Quito, Ecuador, this paper examines two questions: What is driving cities to initiate climate adaptation planning? What is enabling the efforts of early adapters to take root? Scholars argue that incentives from external sources such as regulations and funder requirements, the diffusion of international knowledge and norms, and the presence of sufficient capacity are critical drivers of sub-national change in the policy and planning arenas. However, rather then being driven by external pressures, the early adapters examined in this study were motivated by internal incentives, ideas and knowledge generated through local demonstration projects and local networks, and the means to link adaptation to ongoing programs and enlist the support of diverse stakeholders from within the city.

*Corresponding author: jcarmin@MIT.EDU

1. INTRODUCTION

Cities throughout the world have begun to experience the impacts of climate change. As temperatures and precipitation patterns continue to shift, it is expected that urban areas will encounter an even greater array of challenges (IPCC 2007). Increases in the volume of rainfall, intensity of storms, and incidence of natural disasters, for example, will put additional stress on infrastructure, buildings, environmental conditions, and urban services and management systems. To retain their vitality and viability, cities must be prepared for the ways in which they will be affected by climate change. Since international protocols have not been advanced for adaptation planning at the local level, and most national governments are not working to address potential problems at this scale, some cities are taking independent action to initiate adaptation (Granberg and Elander 2007; Schreurs 2008)

Local climate adaptation efforts tend to emphasize one of three goals: accommodating, protecting, or retreating. For instance, managing the impacts of sea level rise include accommodation strategies such as beach nourishment, the installation of protective structures such as groins and seawalls, and retreat measures that restrict development and other human activity, including provisions to relocate current residents (Kirshen, Knee, and Ruth 2008). While adaptation measures typically are aligned with one or more of these approaches, the extent to which they are being formally integrated into citywide planning efforts tends to vary. At one extreme, cities are developing comprehensive plans for adaptation. However, these efforts are the exception rather than the rule. The more common approaches are for sector-based departments to identify key threats and related measures they need to pursue or for no adaptation planning to be taking place.

What is driving cities to initiate climate adaptation planning? What is enabling the efforts of early adapters to take root? In this paper, we draw on theories of diffusion and capacity, and field research in Durban, South Africa and Quito, Ecuador, to advance our understanding of what is leading cities to engage in climate adaptation planning. Although scholars have begun to integrate issues related to climate adaptation into their research agendas, the emphasis has been on the range of adaptation options that are viable to pursue (Smit et al. 2000), the costs and benefits of implementing different measures (Tol et al. 2004), and the needs of vulnerable countries and populations (Adger et al. 2006; Roberts and Parks 2007). While these studies are important, they do not consider the preconditions for climate adaptation planning or assess adaptation in urban contexts. Therefore, in the sections that follow, we discuss drivers of urban change and present case studies of Durban and Quito to advance our understanding of the forces and factors associated with climate adaptation planning in cities.

2. POTENTIAL DRIVERS OF URBAN CLIMATE ADAPTATION PLANNING

Minimizing the impacts that climate change will have on cities and their inhabitants requires that urban municipalities make concerted efforts to protect natural systems, the built environment, and human populations. For most cities, a commitment to adaptation requires adjustments in the institutional frameworks guiding their decisions and actions. There are three sets of factors associated with institutional change in cities that are relevant to the adoption of climate adaptation planning. The first two factors, incentives and ideas, often are attributed to the spread and adoption of innovation in the policy and planning arenas (Dobbin, Simmons, and Garttre 2007). In addition, resource-based studies suggest that a third factor, capacity, affects the ability of a city to initiate and sustain a municipal program of action.

2.1 Incentives for Adaptation Planning

Incentives motivate urban change through the promise of rewards. In some instances, these rewards are predicated on meeting conditions established by external parties (DiMaggio and Powell 1983; Dobbin, Simmons, and Garttre 2007). This often is the case, for instance, with regulation and funding. Regulations traditionally impose requirements and use the threat of sanctions to foster compliance. Although this is one of the methods countries use to shape local behavior, regulations addressing adaptation at the local level have not emerged, even in countries that have prepared national adaptation plans. As with regulation, funding often is accompanied by requirements that must be fulfilled. At the present time, funding that is earmarked for adaptation is limited. Bilateral development assistance and foundations are common sources of project-level aid, some of which is being linked to adaptation. It is anticipated that development loans and aid channeled through international organizations will play an increasing role in supporting urban adaptation. Funding can directly support adaptation initiatives. It also can be an indirect catalyst for adaptation when it contains related requirements. For instance, a city may obtain a loan for infrastructure, but the financing may be predicated on meeting other stipulations. While conditionality in the environmental arena is common, and some funders are starting to incorporate climate-related provisions, adaptation is not a requirement in most funding streams (Gutner 2002; Tellum 2007; Hicks et al. 2008).

Most scholars emphasize how external pressures promote urban change. However, for many cities, internal goals serve as incentives for initiating new programs or initiatives. Being able to demonstrate leadership or offering an environment that is conducive to business and residents is a driver of action in many locales. A further incentive that is relevant to climate protection is the presence of threats to residents, assets, and the general development goals of a city. Natural disasters and sudden events often give issues sufficient visibility to move them on to the policy agenda and, in some cases, to foster change (Kingdon 1995; Birkland 1997). In some instances, weather events and disasters have been attributed to climatic change and contributed to a city engaging in climate action planning (Zaharan et al. 2008a, 2008b). As these patterns suggest, the desire to protect property and local populations also may be an incentive for initiating adaptation planning.

2.2 Ideas and Adaptation Planning

Ideas in the context of adaptation planning refer to the ways in which knowledge alters local behavior (Dobbin, Simmons, & Garttre 2007). While incentives rely on the promise of benefits, ideas promote change by transmitting information and norms, both within and across countries (Strang & Meyer, 1993). The diffusion of ideas, such as best practices, standards, and conventional wisdom, influence behavior in cities by generating an awareness and understanding of activities that are most appropriate and likely to achieve a desired outcome (DiMaggio and Powell 1983; Scott 1995). Diffusion in the climate arena is not limited to knowledge related to planning processes and techniques, but includes the transmission of scientific knowledge and information that can affect perceptions of risk. While diffusion can take place within and across countries, most scholarly work focuses on how international and global ideas shape action in sub-national arenas (e.g., Stone 2004; Dobbin, Simmons, and Garttre 2007)

Diffusion can be initiated from a variety of sources. Professional networks and associations often transmit ideas and information to their participants and members. In the climate arena, the International Council for Local Environmental Initiatives (ICLEI-Local Governments for Sustainability), United Cities and Local Governments (UCLG), C40 Cities, and Cities Alliance are among the many formal networks and umbrella organizations that provide information about climate change to member cities through electronic media, publications, and the meetings they convene. The diffusion of technical expertise and managerial know-how also can occur when representatives from a city participate in governmental and intergovernmental initiatives such as domestic and international commissions and in events such as conferences and training programs. Incentives are not the only tool used by international organizations to promote change. The UN, OECD, World Bank, and others foster the transfer of norms and ideas through publications, workshops, meetings, training programs, and technical assistance (Stone 2004).

NGOs and consultants are further sources of diffusion in the urban context since many provide services and support the efforts of local governments. In the climate arena, environmental, development, and humanitarian aid organizations are among the NGOs that have the potential to be most influential. While some of these organizations conduct their own research, others maintain their expertise in their respective policy domains by staying current in the relevant literature and attending conferences and training sessions. As they interact with local governments, be it through in person contact as they collaborate, advocate, and protest, or through policy papers and reports, NGOs can diffuse ideas and practices they believe will be effective (Princen 1994; Boli and Thomas 1999). In the climate arena, natural scientists and engineers also are important sources of diffusion as they disseminate knowledge about the potential impact of climate stressors as well as the ability that a city has to withstand these impacts (Jasanoff 2005).

2.3 Capacity for Climate Adaptation

Local capacity, including financial, technological, human, political, and social resources, provide a foundation for initiating and sustaining change (Clemens and Cook 1999). From a practical standpoint, the financial stability and security of a city will affect its ability and willingness to tackle new initiatives as some adaptation measures, such as infrastructure upgrades and residential resettlements, require major investments. Technology also will affect a city's adaptation planning. Those that have advanced capabilities are able to conduct spatial analyses of vulnerabilities and develop models and scenarios, all of which make is possible to assess a variety of options before making decisions and taking action.

Human resources are not limited to personnel dedicated to working on climate issues, but extend to the presence of leadership. Time and again, a change or new initiative has been attributed to the efforts of a local champion, including those in the climate arena. Leadership in these instances has been demonstrated by elected officials, government employees, and local residents (Mukheibir and Ziervogel 2007; Roberts, 2008; Schreurs 2008). Leadership can manifest at the city level. For instance, programs that demonstrate a commitment toward protecting the environment and enhancing sustainability, including those dedicated to smart growth, green building, and open space conservation, suggest that a city is environmentally proactive. They also provide a resource on which adaptation efforts can be built. Leadership further extends to the presence of political will to promote the ideas advanced by champions and sustain existing programs and initiate those that are new.

Transnational and national NGOs, as well as local NGOs, CBOs, and residents, contribute to the human and social dimensions of urban adaptation capacity (Few, Brown, and Tompkins 2007). A variety of transnational and national environmental, humanitarian aid, and international development NGOs have initatied programs and projects that advance preparedness for the impacts of climate change in cities. These include preserving ecosystems as a means to minimze the impacts of natural disasters, ensuring that poor communities have flood defenses and early warning systems in place, and improving stores of food, water, and medical provisions (Reeve, Anguelovski, and Carmin 2008). In some cities, particularly those in developing countries that are highly vulnerable, communities are extending local capacity by participating in risk assessments (van Aalsta, Cannon, and Burton 2008) and taking steps to ensure they are prepared for climate impacts (Jones & Rahman 2007; Sabates-Wheller, Mitchell, and Ellis 2008). While these locally-initiated efforts are being made by vulnerable communities to address issues they are facing, they contribute to urban capacity and promote and sustain city adaptation planning.

3. URBAN CLIMATE ADAPTATION PLANNING IN THE GLOBAL SOUTH

As the previous discussion suggests, incentives, ideas, and capacity can foster institutional change in cities. Incentives create imperatives. In some instances they are a response to external pressures stemming from sources such as regulation and funder requirements. In other instances they are based on internal goals such as developing a competitive advantage or protecting environmental quality. Ideas transmit information and knowledge about relevant, appropriate, efficient, and effective initiatives for a city to pursue. Collectively, incentives and ideas serve as catalysts that alter the institutional field by establishing room for new actors to emerge and for entrepreneurial efforts to influence existing rules and norms (Greenwood, Suddaby, and Hinings 2002). Alternatively, financial, technological, human, and social resources affect the extent to which the status quo can be maintained and new initiatives adopted and implemented (Clemens and Cook 1999).

Incentives, ideas, and capacity will be present in all cities in one form or another. However, our understanding of how these factors shape the earliest phases of policy formation and implementation is limited. Therefore, we studied two cities that are early leaders in climate adaptation planning: Durban, South Africa and Quito, Ecuador. In addition to both cities engaging in adaptation planning, they are experiencing natural disasters and natural resource depletion and wrestling with longstanding challenges associated with poverty alleviation, infrastructure upgrading, and basic service provision.

The narratives that follow were primarily developed from semi-structured interviews and participant observation. The Quito case is based on in-person and telephone interviews with staff members and managers from departments working on climate adaptation and local elected officials who played a central role in the adaptation planning process. Since one of the authors (Roberts) was instrumental in the adaptation planning process in Durban, this case initially was based on her observations and experience. To minimize bias and verify factual information and interpretations, we conducted additional interviews with city employees. In both cases, we engaged in follow-up email exchanges to confirm or clarify important information with respondents. To further validate our understanding of the chronology and drivers of planning, the cases were reviewed by individuals from each city who were involved in the planning process. We begin each narrative with overview of the city and its adaptation initiatives. We then examine the types of incentives, ideas, and resources that were present and the ways in which they shaped urban adaptation planning.

3.1 Climate Adaptation in Durban, South Africa

The city of Durban covers an area of 2,300 kilometers and has a population of approximately 3.5 million people. This expansive municipality has varied terrain that ranges from a flat coastal plain in the east to steep escarpments and undulating hills in the west. Durban's climate is subtropical with an annual average rainfall in excess of 1000mm. The variety of landforms and climatic conditions within the municipal area, along with it being located within a biodiversity hotspot of national and international significance, have produced a wide range of terrestrial and aquatic ecosystems. Within the city's boundaries are three terrestrial biomes (savanna, forest, and grassland), 18 major river catchments, 16 estuaries, and 97km of coastline. Durban also is a culturally and racially diverse city with African, Asian, and European influences. The Black African community makes up the largest sector of the population (68%) followed by the Indian community (20%), the White community (9%) and the Colored community (3%). Spatially Durban is still affected by the legacy of apartheid development with a racially structured, highly fragmented, sprawling, and poorly integrated urban form.

The advent of democracy in South Africa in 1994 brought with it enormous development pressures and expectations. Most of these were linked to the need to address the socio-economic imbalances of the country's past. Racially-based apartheid development policies created high levels of structural unemployment and large numbers of underinvested and un-serviced households. Addressing these shortfalls poses an ongoing challenge to local governments throughout South Africa. Even through Durban is an important economic center in South Africa, 34.4% of the working age population currently is unemployed. This has contributed to high levels of poverty and crime in the city. Further, many government institutions are inefficient and ineffective. While efforts are being made to address service backlogs, at present there are 140,000 urban households that do not have access to services such as water, electricity, and sanitation.

Durban is planned and managed by the eThekwini Municipality. Politically eThekwini Municipality is overseen by a non-executive Mayor and an Executive Committee. The Executive Committee is the principle committee of the municipality. There are 200 councilors and one hundred wards. The Administration is headed by a City Manager and is divided into six functional clusters, each with their own dedicated deputy City Manager**.** Given the immediacy of many problems, the city has placed a priority on traditional forms of economic development and basic service provision. The development objectives for the city are summarized in the Integrated Development Plan (IDP). The IDP outlines the need for development that balances social, economic and environmental needs. The vision articulated in the IDP is that "By 2020, eThekwini Municipality will be Africa's most caring and livable city." To achieve this vision, a number of key developmental choices have been made. These include improving the port and logistics infrastructure, using land use management to increase densities and to reduce sprawl, improving the public transport system, developing ecological tourism, and ensuring ecological integrity.

Relative to other more immediate and clearly defined challenges that the city faces, climate change has not received significant attention, mainly because its impacts are viewed as more remote and uncertain. However, an initial impact assessment commissioned by the Environmental Management Department (EMD) in 2004 suggested that there are many imminent threats posed by climate change and that these will affect the city's economic stability and development. The assessment indicated that in the years to come, Durban will likely experience temperature increases of 2-3°C in maximum temperatures and 3-4ºC in minimum temperatures. There is some indication that the total amount of rainfall may increase and that the seasonal distribution will change. Current measurements suggest that sea level is rising, on average, by 2.7 cm each decade. The predicted changes in temperature, precipitation, and sea level will likely be accompanied by a host of impacts. These range from heightened frequency and intensity of floods and droughts to increased rates of coastal erosion and levels of stress on existing infrastructure, to decreased water availability and food security. Changes such as these affect most municipal functions and undermine the city's stated goal of achieving a more sustainable development path, including its potential to address the needs of previously disadvantaged communities.

3.1.1 Adaptation Planning Process in Durban

Climate-related action in Durban was initiated in 2000 when international funding was made available for a small number of South African local governments to participate in ICLEI's international Cities for Climate Protection (CCP) campaign. Among the achievements resulting from participation in the program were the development of a municipal Greenhouse Gas emissions inventory and the initiation of an energy efficiency program for select municipal buildings. Despite these gains, very little knowledge of climate science or the impacts of climate change on municipal functions was learned in the process. As a result, the CCP campaign generated only minimal levels of interest and momentum with respect to climate action in the municipality.

The situation began to change in 2004 after Debra Roberts, Head of the EMD, returned from a semester-long environmental management program at Brown University in Rhode Island (USA). The course she attended was designed for professionals in leadership positions in the global South and included in-depth engagement with climate science. Roberts' new understanding of climate change and its implications for the city were critical factors in her initiation and development of the Municipality's Climate Protection Programme (MCPP) upon her return. At that time, she also commissioned consultants through the EMD to conduct an initial climate change impact assessment. The completed assessment was published in 2006 as a report entitled, *Climatic Future for Durban*. This report provided the first real opportunity to engage diverse municipal stakeholders in discussions about climate change. The presentations she gave to city councilors highlighted the fact that there was nascent political interest in understanding how the city could respond and adapt to anticipated changes.

The assessment and report generated sufficient interest that Roberts, working through the EMD, initiated development of an adaptation strategy for the city in 2006. This involved having extensive discussions with municipal line departments to ascertain the extent that municipal sectors were vulnerable to climate change impacts, the ways that various departments of the municipality could engage with climate adaptation, and the types of departmental options and initiatives already in place that would facilitate adaptation. The process resulted in the publication of a summary document later that same year called the *Headline Municipal Adaptation Strategy* that highlights the relevance of climate-change issues for virtually all departments within the municipality and presents broad strategic targets for each sector.

The *Headline Adaptation Strategy* was integral to advancing adaptation planning in Durban. However, since this document is limited to general guidelines, it has become clear that most departments are not using it as a point of reference or taking concerted action to consider climate impacts in their decisions or actions. Once again taking the lead, the EMD is in the process of developing sector specific Municipal Adaptation Plans (MAPs). While all sectors ultimately will be included, in this early phase, the water and health sectors are the focus since they have been identified as two areas that face the greatest risk of being directly affected by climate change. Rather than emphasizing broad strategic targets, the intention with the MAPs is to ensure that adaptation is fully integrated into the planning, activities, and decisions of the affected line functions. The MAPs, which are expected to take approximately 12 months to develop, will include detailed action plans that will maintain or improve the functioning of municipal systems, departments, services, and infrastructure as the local climate changes (ERM 2008). They also will contain clear target dates for the roll-out of action plans, be developed with and approved by affected municipal departments and key stakeholder groups responsible for plan implementation, and be approved by the city council.

3.1.2 Drivers of Adaptation Planning in Durban

Addressing climate change at the city scale in South Africa is challenging due to the administrative structure of the country. Although South Africa has ratified the UNFCCC, it has not yet converted the relevant elements into national law and therefore, addressing climate change is not yet mandatory (DEAT/UNDP 2008). As a result, municipalities must take independent action if they want to pursue climate mitigation and adaptation agendas. The preparation of the *Climatic Future for Durban* and *Headline Adaptation Strategy* were influential reports that helped set the adaptation planning process in motion. While these reports can be traced to the early efforts Roberts made to initiate climate initiatives in the city, a number of incentives and ideas influenced her activities as well as the acceptance of climate change by city officials as an issue worthy of being placed on the municipal agenda.

Incentives for Planning in Durban

A view often advanced about policy and planning is that change is motivated through mandates, such as requirements stemming from national laws or donor funding. However, this form of pressure was not a driver of Durban's adaptation action. When climate adaptation planning was initiated, there were no national or provincial policies or laws that required cities in South Africa to pursue adaptation planning. There also have not been any pressures to pursue adaptation associated with direct foreign investment and official development assistance. At the time Durban was initiating its planning process, most funders had not started to support adaptation-related initiatives. Even in subsequent years, financial support from governments and foundations has not been earmarked for adaptation or contained adaptation requirements.

Durban has been highly successful in obtaining grants and using them to support its climate-related efforts. In other words, rather than external funders establishing an adaptation agenda, Durban has found ways to link international funding to their adaptation program and use them to realize their ideas. For example, when it became clear that the H*eadline Adaptation Strategy* was not leading to changes in the way that sectors and departments were going about their work, Roberts wanted to find a way to initiate more detailed adaptation planning as a way to catalyze action. Coincidentally, she was invited by the Rockefeller Foundation to attend a meeting and present her work. That was followed by an invitation to sit on the Advisory committee for their Asian Cities Climate Change Resilience Network (ACCCRN). Because time spent on the network would take her away from her local work from time to time, Rockefeller offered to compensate her either through an honorarium or by allocating money for local projects. She elected to use those funds to jumpstart the MAP work.

As in other parts of Africa, storms have come to be accepted as normal weather patterns in Durban. There is no concrete evidence that they are related to climate change. However, as awareness of climate risks grow, and as Durban experiences frequent floods and significant coastal damage, the storms reinforce claims that climate change is real and that the city needs to pursue adaptation planning in order to protect its residents and property and to make progress on the development path elaborated in the IDP. The IDP elaborates the city's development objectives and is a point of reference for many of its decisions. The IDP not only emphasizes improving infrastructure and the provision of municipal services, it also stresses the importance of promoting equity by attending to the needs of vulnerable populations. Engaging in adaptation activities are seen by some as a means of protecting vulnerable populations while supporting the projected development path.

Ideas and Adaptation Planning in Durban

The first phase of the MCPP, the vulnerability assessment, focused on understanding how climate change would affect Durban and municipal operations more broadly. Since information on the ways in which global environmental trends would play out in the city were not available, this was an important first step in ascertaining the city's vulnerabilities and the implications of changing climatic conditions for security and stability over the long term. The potential severity and cross-cutting nature of the impacts highlighted by the impact assessment underscored the urgent need to ensure climate change issues were considered in all aspects of city planning and development.

International networks often are attributed with being sources of influential ideas. Durban has developed ties to some of these types of networks and they have had some impact on adaptation planning. For instance, Durban developed an affiliation with ICLEI in 1994. At that time, ICLEI was focusing on Local Agenda 21 rather than climate change and Durban participated in the network in order to become integrated into the international environmental community. Although ICLEI did not have any impact on adaptation planning per se, it did help representatives from the city build their environmental networks and sources of information. Training sessions often can diffuse ideas and information that shape actions. This was the case when senior managers from several municipal departments in Durban participated in programs led by international agencies to help them prepare for emergencies. For instance, the United Nations invited Debra Roberts from the EMD and Billy Keeves from the Disaster and Risk department to participate in Awareness and Preparation for Emergency at Local Level (APELL) workshops to better prepare the city for emergencies that could impact industrial and technical sectors.

The earliest climate work in Durban was due to the efforts Roberts, who was committed to the cause and willing to explore unfamiliar terrain such as developing impact assessments. This started to change as more targeted opportunities arose. For instance, in addition to the ACCCRN providing links to others in the international community who were thinking about climate adaptation and resilience, Roberts also forged ties with the Tyndall Centre for Climate Change Research in the UK while attending a conference in Mexico. This led to an informal partnership between the Tyndall Centre and eThekwini Municipality to develop integrative assessment tools for London and Durban, respectively. As with international networks, this partnership has allowed Durban to engage others who are thinking about similar issues and to share and test ideas that support their climate work.

Durban is not the only city in South Africa that has been pursuing climate adaptation. Other major metropolitan areas such as Cape Town and Johannesburg as well as smaller centers such as Potchefstroom have emerged as climate leaders. At the present time, there is no structured coordination or communication between these different communities and therefore, no domestic efforts to promote joint learning or sharing of best practices. Instead, Durban and other local governments are obtaining information about adaptation from reading reports, scanning the Internet, and talking to people at conferences and meetings. Working with consultants is also an important source of learning. In many instances, consultants are hired to assist or prepare reports. In the process, they often bring new knowledge and ideas to the municipality. This was the case with the preparation of the *Climatic Future for Durban* report which summarized, for the first time, locally relevant climate change research being undertaken in South Africa in a single, accessible document. By engaging consultants, local government officials were able to obtain information that they would not have the time or resources to obtain for themselves.

Rather than adaptation initiatives following a predetermined course, many ideas and activities tend to be the result of unexpected opportunities. For instance, Roberts gave a lecture on climate change at a public seminar. At the conclusion of the event, an individual with a passion for green roofs spoke with her about their potential and she realized that this could be an interesting idea to test in the city. The city has an extensive stock of large, flat, and empty rooftops on its buildings (Greenstone, 2008). These spaces are ideal locations to create green roofs and could be used to develop a network of green spaces in the inner city environment that could provide a range of adaptation benefits such as reducing urban heat island effects, slowing runoff, and improving food security. Roberts was able to allocate modest funds and provide institutional support to start testing this idea. The only way to get access to the city's building stock was to forge a partnership with the Architecture Department. The result is that the EMD and the municipality's Architecture Department are developing a green roof on an existing municipal building within the central business district. This project will test the methodology and measure the effectiveness of the installation in terms of temperature amelioration and storm water management. Should this pilot prove to be successful, the potential exists to roll out the project to other municipal buildings and proposed new developments. In the process, it also may mean that ideas about climate adaptation will be diffused internally in the city.

Capacity for Adaptation in Durban

Much of the climate work in eThekwini Municipality has been undertaken by the EMD on a part-time basis and implemented with department funding that was able to be reallocated from core biodiversity projects to adaptation. Despite limited financial and human resources, the initiatives undertaken by the EMD have achieved local, national, and international recognition. In 2007, these efforts were formally acknowledged and institutionalized by the municipality with the creation of a dedicated Climate Protection Branch within the EMD. Although this is an important step forward, as is the case with municipal jobs in Durban in general, it has been difficult to find someone willing to fill the new post due to its low level grading and salary package. The result is that in the short-term, the climate work undertaken by the EMD continues to be done in an *ad hoc* manner, as time and resources permit. Although efforts are not widespread, other departments ranging from health, to disaster management, to food to coastal management, have begun to address adaptation. Since internal capacity is limited, departments rely on their personnel to the extent it is feasible to do so and outsource the remainder of the work to consultants.

Previous research suggests that cities with ongoing environmental initiatives are likely to be early adopters in the climate mitigation arena. If Durban is a reflection of other cities, then this also appears to be the case when it comes to adaptation. A variety of environmental programs in Durban created the foundation on which current adaptation efforts are being built. In addition to drawing on some of its existing programs, the municipality has been able to engage members of local communities and other stakeholders in their adaptation efforts. In this regard, a number of projects have been initiated under the banner of Community Adaptation Planning (CAPs). For instance, the Climate-Smart Local Communities project aims to improve adaptive capacity in poor communities. The two communities participating in this program will be involved in conducting vulnerability and risk evaluations, and then using this information to develop and implement sustainable cross-cutting adaptation measures. The local participants in the program include formal community leadership, such as ward Councilors, civil society representatives, women's groups, communal garden committees, and school groups. If the program is successful, then it will be initiated in other communities in the city (Golder Associates 2008).

Pilot projects implemented by consultants on behalf of the municipality also assist the local government in better targeting its efforts. For example, research undertaken within the MCPP indicated that rural and peri-urban low-income groups in Durban grow approximately 50% of their food, and purchase the remainder. The predominant food purchased is maize and costs families in excess of 50% of their monthly income. This poses significant challenges as the predicted changes in weather and temperature Durban indicate that the productivity of agricultural land, particularly for maize, will decrease in the future. Alternative food production will therefore be required to ensure food security for the city's low-income groups. The municipality has initiated field trials in different climatic zones that simulate conditions projected by various climate change scenarios. At each testing station, a variety of crops will be planted and yields will be measured at the end of the growing season. In parallel to the field trials, the social acceptability of the new crops will be tested to determine the ability of the average household to prepare the new foods, the palatability of the food, and its acceptability as a substitute for maize (Golder Associates 2008). The findings of this project will inform the development of food security plans and strategies in the city.

A number of local NGOs are working collaboratively with the city to support its climate and development goals. This is evidenced, for instance, with a successful community reforestation project. The project site selected for this intervention is the regional Buffelsdraai landfill to the north of the city where the municipality has extensive land holdings. This land was once forested and wooded, but is currently under sugar cane cultivation. Working in collaboration with the NGO, Wildlands Conservation Trust, the city is promoting the Indigenous Trees for Life (ITFL) program as it provides a platform for the development and implementation of the Buffelsdraai Community Reforestation Project. The objective of ITLF is to establish sustainable livelihoods that contribute to the restoration of the region's forest ecosystems and to the sequestration of carbon dioxide. The program draws on a network of 'tree-preneurs,' often orphaned and vulnerable children, who grow indigenous trees and then barter the trees for food, clothes, bicycles and other necessities that the Trust secures through corporate donations. The trees are then replanted in urban greening projects or forest restoration carbon sinks (Diederichs 2008).

Informal networks exist across most municipal departments and among many individuals. These relationships have provided a foundation for advancing adaptation planning. This was the case, for instance, in the creation of the MAPs. Roberts targeted the most vulnerable sectors and invited key individuals to a meeting to discuss their involvement. However, it is important to acknowledge that networks alone do not ensure participation or commitment to adaptation planning. Some departments maintain that they do not have the capacity to address adaptation. Others believe that adaptation measures will compete with their priorities. For instance, some individuals working in the area of economic development are concerned that adaptation policies requiring retreat from the coastline would undermine their efforts to promote tourism. As a result, while networks foster communication and can facilitate coordination, there are varying views of the value of adaptation relative to the economic and social priorities in the city.

3.2 Climate Adaptation in Quito, Ecuador

Quito, home to approximately 2.1 million people, is situated 2,800 meters above sea level in the Central Andes of South America. While the natural mountain barriers create a spectacular setting, they have forced urban development to follow a linear trajectory and urban growth to be highly chaotic. The result is that the city is approximately 40 to 50 km in length from North to South, but only between four and ten kilometers wide from West to East (World Bank 2008). As is the case with other Latin American cities such as Bogota and Curitiba, Quito has made strides in protecting environmental quality. This is exhibited in the presence of electric bus systems that run along dedicated corridors and have the potential to be upgraded to a light rail system. It also is reflected in the preservation of over 50% of the metropolitan region as green space and in initiatives ranging from slope protection to the creation of formal parks to air quality monitoring systems.

Average GDP per capita in Quito is low, with 30% of the people living in poverty. Most of the poor are concentrated in upgraded informal settlements to the south of the metropolitan area (World Bank 2008). There is a long history of migrants moving from agricultural areas to the edges of the city. In the past, these migrants would create illegal settlements. However, this is increasingly rare due to a greater number of shelters and city-owned housing in conjunction with tough sanctions against squatting. Just as the poor have their enclaves, so too do the wealthy. While some live in the urban core, many have moved to the suburban areas in the northeastern hills that surround the city center. In contrast to settlements in the south, the wealthy neighborhoods in the northeast are populated by well-tended homes that boast high levels of amenities and easy access to shopping centers, offices, and recreation areas.

The Municipality of Quito, which is situated within the broader Metropolitan District, is governed by a Metropolitan Mayor and a Municipal Council. As a result, most of the planning and regulatory power for the Municipality lies in the hands of the Metropolitan Council for the District of Quito. The Metropolitan Council approves ordinances, resolutions, agreements, and leads broader projects for the whole metropolitan area, including the Municipality of Quito.

Although Quito is flourishing, it faces a wide range of challenges as it slowly emerges from a national economic crisis that accumulated and worsened with the dollarization in 2000. Among the city's highest priorities are the construction of a viable waste treatment system, the creation of new suburban centers and affordable housing, and the promotion of nature and cultural tourism. Transportation also is a pressing issue. There is a strong need to develop new arterial roads and tunnels as well as to implement the proposed light rail system. Even though the municipality is projecting a rapid increase in revenues and public expenditures, city departments do not expect to have sufficient resources over the next decade to address all of the major issues identified in the Metropolitan Structural Plan.

The impact of global climate change is among the challenges that Quito is working to address. In the Andean region where the city is located, the temperature has been increasing by about 0.11°C per decade against a global increase of 0.06°C per decade (Gobierno del Ecuador et. Al. 2008). As with the rest of Ecuador, because of its geographic position and mountainous topography, Quito's water resources are highly vulnerable to these changes in temperature (Comité Nacional sobre el Clima 2001). The city relies on melt and water resources in glacial basins and páramos ecosystems for about 50% of its water supply. For instance, Quito receives part of its potable water provision from the Antisana Glacier and its páramos ecosystems. Changes in climatic conditions are associated with this glacier decreasing about 7 or 8 times faster in the 1990s than in the previous decades (Francou et al. 2000, Maisinchi et al. 2005). As temperature rises, and the rate of glacial melt increases, the long term availability of water to the city is decreasing.

The impacts of climate change are not limited to water availability. Public officials also anticipate that changes in temperature will contribute to the destruction of endemic habitat and biodiversity, the release of carbon from páramo soils, increased likelihood of fires and desertification, and lower agricultural yields (World Bank 2006; Dirección Metropolitana Ambiental y Fondo Ambiental 2008). The intensification of extreme rainfall in Quito also will place additional stress on down slope habitats, including primary rainforests, exacerbate flooding, and lead to increased occurrences of landslides and mudslides (Dirección Metropolitana Ambiental y Fondo Ambiental 2008).

3.2.1 Adaptation Planning Process in Quito

In fall 2006, the mayor at the time, Paco Moncayo, and the Metropolitan Council decided host a one-time regional conference of the Andean Community of Nations called Clima Latino. The conference, scheduled for October 2007, was designed to bring representatives from local and national governments together to start thinking about the impacts of climate change in the Andean Community and identify measures they could take to promote mitigation and adaptation. Given the significance of the event, and the desire to demonstrate that they were a proactive municipality, Mayor Moncayo and the Metropolitan Council thought the conference would be a good platform for highlighting climate initiatives taking place in Quito.

The decision to host the conference immediately initiated discussions about climate planning, but the process did not gain momentum for a few more months. In January of 2007, Gonzalo Ortiz gave a presentation to his fellow members of the Metropolitan Council about the importance of designing a climate strategy for Quito based on scientific information about rising temperatures and the shrinking of the Andean glaciers. He argued that it was imperative for Quito to establish both mitigation and adaptation strategies. This presentation generated wide and warm support from the Council and Mayor Moncayo. Based on these approvals, less than a month later, Ortiz initiated the formal planning process when he and Carmen Elena De Janón, another Metropolitan Councillor, asked the Directors of the municipal water and sewage corporation (EMAAP-Q), the municipal air monitoring corporation (CORPAIRE), the Metropolitan Office for the Environment, and the Strategic Research Unit to establish an Inter-Institutional Commission and prepare a draft climate change strategy for the city. Their charge was to summarize the best available knowledge on climate adaptation and mitigation and propose concrete measures that the city could follow.

In September 2007, the Inter-Institutional Commission shared its draft strategy with key technical representatives from different municipal agencies and received their approval in October 2007. This draft document was presented at the Clima Latino conference a few weeks later. Discussions that took place at the conference helped improve the quality of the draft, especially the sections on objectives and guidelines for climate adaptation and mitigation. Once this preliminary stage in planning was complete, Quito engaged in a metropolitan-wide consultation about the plan. The Commission decided to hire an environmental NGO, ECOLEX, to formally lead the consultation process. ECOLEX was charged with engaging the local population, especially vulnerable communities living on the hillsides of the Pichincha Volcano, the Valle de Los Chillos, and other poor neighborhoods in the Southern part of Quito, as well as key social and community development organizations. Four workshops were held by ECOLEX in October and November 2007 to gather concerns and suggestions so that they could be addressed in the climate strategy. While many issues and suggestions were raised, the major concerns voiced by the general population were the need for access to public transportation as well as better waste management, hillside protection, and improvements to the potable water system.

After making revisions based on the concerns and suggestions voiced by residents, a formal document called the *Quito Strategy for Climate Change* (EQCC) was finalized in February 2008. The EQCC, which is presently pending formal adoption and integration into local regulations of the Metropolitan District, addresses activities in four Strategic Areas: (1) Communication, education and citizen participation in climate change efforts; (2) Institutionalization and capacity building for climate change in the Metropolitan District of Quito; (3) Ensuring adequate information to decrease vulnerability and promote adaptation; and (4) Use of technology and good environmental practices to reduce and capture GHGs in five sectors (energy, industrial processes, agriculture and farming, waste, and land use and forestry). The plan maps out activities across sectors with varying degrees of specificity, but does not establish concrete deadlines and targets.

An entire Strategic Area of the EQCC is dedicated to elaborating measures that will guide Quito towards being prepared for the impacts of climate change. Among the adaptation measures included in the plan are the development of an Environmental Information System that will inform citizens of the most important current and future climate risks and impacts. It also establishes broad guidelines for developing Early Warning Systems and a Climate Risk Management System (Dirección Metropolitana Ambiental y Fondo Ambiental 2008). The strategy is designed to be flexible, with provisions for ongoing monitoring and evaluation so that the city can readjust its adaptation measures over time as appropriate. It also is oriented toward broad stakeholder engagement. Not only does it consider the role of government agencies in preparing the city for climate impacts, but also the ways in which university engagement, civil society participation, and public-private cooperation can support and sustain adaptation initiatives (Dumas 2007).

3.2.2 Drivers of Adaptation Planning in Quito

National climate efforts in Ecuador stretch back to the early 1990s when the country ratified the UNFCCC. Over the years, efforts have been made to implement mitigation projects and develop a national plan. Working under the auspices of the Ministry of the Environment and the National Climate Change Committee, Ecuador developed its *National Policy and Strategy for Climate Change* in 1998 and currently is in the process of constructing a National Climate Change Adaptation Strategy. However, most national climate policies do not extend their reach in a concrete way to cities or other local areas.

The *Quito Strategy for Climate Change* was set in motion when the Mayor and members of the Metropolitan Council decided to host the Clima Latino conference and then formalized in response to the call for action made by Gonzalo Ortiz. Since his presentation to the Metropolitan Council in January 2007, Ortiz has served as a champion for climate change planning and has encouraged local agencies and offices to adapt concrete measures. However, he has not been alone in his quest. Other municipal leaders and officials initially supported the creation of the climate strategy and continue to be proactive in advocating for programs that strengthen the resilience of Quito against changing climatic conditions. Rather than wait for the national government to pass legislation, provide structural guidance on adaptation priorities and measures, or offer support for their efforts, local officials realized that they should not delay further adaptation planning and elected to take independent action. Collectively, their awareness and ability to initiate adaptation efforts was shaped by a number of different incentives, ideas, and the overall capacity within the city to support and sustain adaptation planning and implementation.

Incentives for Planning in Quito

Institutional change often is associated with the presence of incentives, either in the form of regulations or funder pressures. However, this was not the case with respect to adaptation planning in Quito. As mentioned earlier, the city was not pressured by the national government to pursue particular projects or planning measures. Further, while Quito recently has been able to avail itself of support from international funding agencies, this was sought out by officials to advance adaptation work that was being planned, rather than funders imposing their requirements on Quito. For instance, the Andean Regional Project for Adaptation to Climate Change studies and monitors the environmental conditions and ecosystems around the micro-basins of the Antisana Volcano. In this project, the EMAAP-Q receives funding from the GEF and World Bank to collaborate with scientists from the Project. The goal is for EMAAP-Q to better understand how changing conditions in the micro-basins will impact water provision and ascertain what adaptation measures are required to ensure adequate potable water distribution in Quito.

A motivating force for the city's adaptation planning efforts is its aim to be regarded as a leader in the Andean region and in Ecuador. This vision, and related efforts to enhance the visibility of innovative initiatives within the city, led Quito to organize international climate conferences such as Clima Latino. The conference gave them an opportunity to learn from others in the region about their experiences with climate change and get feedback on their draft proposal. While the event was used to legitimize and validate their climate adaptation initiatives, climate initiatives also were a way the city could demonstrate it is taking a leadership role on geopolitically and environmentally important issues.

In addition to organizing conferences, Quito has maintained a presence at international climate conferences to ensure that its accomplishments gain recognition and to bring more visibility to its initiatives. For instance, Guido Mosquera, the head of the Inter-Institutional Commission in charge of the climate change strategy for Quito, wanted to present Quito's climate change strategy at a regular meeting of the Inter-American Network of Cities (Red Ibero-Americana de Ciudades) that was being held in Medellín, Colombia in November 2007. Local officials and members of the Inter-Institutional Commission knew other "competitor" cities would present their climate change work and, once again, they wanted to demonstrate that they were taking a leadership role. By having a draft of their climate strategy in place, they believed that they would be able to show that they were being proactive in protecting the city and its resources against climate threats and extreme weather events. By taking the lead on adaptation planning, they further believed they would reinforce their position as an innovative municipality and would be imitated for their climate and political leadership and autonomous policy-making relative to the national government.

A further incentive for engaging in adaptation planning was an increase in natural disasters and the desire to protect the city from future incidents. A number of early reports suggested that as the climate changed, Quito would be prone to increased periods of rainfall and that these were likely to trigger extreme events such as landslides and floods in the hillside areas around the city. As these predictions came to pass, the need for adaptation planning became evident as weather events affected city functions, particularly public transportation and roadway accessibility. For instance, in May 2006, intense rainfall led to landslides in several residential neighborhoods, damaging houses, obstructing roads, and halting the flow of traffic for several hours (Sánchez 2006). The impacts of severe storms have not been limited to property damage and city functions as earlier that same year a landslide in the Carapungo district resulted in the death of a young man (El Universo 2006).

Ideas and Adaptation Planning in Quito

Awareness of the risk of a changing climate has been influential in Quito. Some of the earliest climate studies date back to the mid-1990s when the French Institute for Development Research (IRD) brought the issue of changing temperatures and its likely impacts to the attention of the Mayor and members of the Municipal Council. One of those reports was based on the results of monitoring of the Antisana glacier. The researchers found that the size of the glacier had significantly shrunk between 1994 and 1997 (Semiond et al. 1998) and therefore, that 80% of the water supply for the city was being threatened. In 2000, study conducted by local university researchers indicating that the population of Quito would double by 2025 caught the attention of EMAAP-Q managers and engineers. Growing sensitivity to the rate of glacial melt, along with population information, served as catalysts for the City Council and the General Manager of the EMAAP-Q to start making provisions to secure the city's water supply.

International workshops and events related to specific sectors, particularly water resources, advanced awareness and understanding of the need to initiate climate adaptation measures in Quito. For instance, over the years, managers from EMAAP-Q and several members of the Municipal Council have been invited to participate in regular meetings of the Inter-American Development Bank, the Corporación Andina de Fomento, and the World Bank related to long-term water security. In the course of exchanging experiences, representatives have learned about some of the problems and the social and political conflicts that have emerged in other locales as a consequence of not being proactive in ensuring adequate water provision. This heightened their sensitivity to the importance of taking action to in Quito. In other international meetings in which the EMAAP-Q participated, such as *the IVth Water Forum in Mexico* and the *First Annual Megacity Water Congress* in 2006, representatives from the water company were able to learn about innovative techniques and approaches for clean, safe, and efficient water supply and management, and water sanitation in large cities. They also become aware of best practices and knowledge management tools from both developed and middle-income countries.

International climate networks and programs also have been influential sources of ideas for the city officials and representatives. Since 2004, Mayor Moncayo has played a leadership role in United Cities and Local Governments (UCLG), contributing to the efforts of this international network and learning from his participation. One example dates to March 2006 when Moncayo served as a member of a delegation from UCLG that participated in the World Water Congress in Beijing. During the congress, debates were centered on the importance for increasing sustainable access to water and sanitation services for urban populations and improving the capacity of local governments and cities to protect and manage water resources. This meeting created a heightened sense of urgency to engage in climate adaptation planning in Quito. Through his involvement in UCLG more broadly, Moncayo has learned how other cities are being affected by climate impacts and the ways they are responding. He has brought these lessons back to Quito where they are shared with members of the Municipal Council and others involved in planning for climate change.

Capacity for Adaptation in Quito

Capacity refers to resources that provide a foundation for adaptation planning and sustain implementation. In Quito, the city's existing environmental commitment and programs planted the seeds for mitigation and adaptation planning. Since the beginning of the 1990s, the mayors of Quito have placed a priority on environmental quality and established a variety of environmental and planning programs. These initiatives include the creation of new parks, river clean-up and restoration, and reforestation. In 2005, Quito's Mayor presented a formal long-term environmental plan (*Plan Equinoccio 21, Quito hacia el 2025*) that encompasses a series of strategic objectives related to recycling, development of clean production technology, control of environmental contamination, and restoration of natural resources in and around Quito. This plan not only serves as guide for programs and projects of relevant metropolitan agencies, but indicates which environmental initiatives should be prioritized. Since these include efforts to protect and restore fragile ecosystems and promote adequate use and conservation of water resources, they establish a basis on which climate adaptation planning in the Metropolitan District is being built.

City offices and departments are important foundations for adaptation initiatives in Quito. For example, knowing that ecological health is essential to water security, the Office for the Environment has been promoting a policy to protect a series of natural areas in the Metropolitan District. In 2006, staff from the environmental office played a strong role in pushing for a municipal ordinance that preserves biodiversity and protects fragile areas and ecosystems around the district since these areas are often sources of water for the population. A number of relevant programs and activities also are situated within the Metropolitan Office for Territorial Planning. Over the years, staff members from this office have been conducting research to identify vulnerable areas of the city and using land use planning measures, such as soil conservation, green space preservation, and forest protection, to reduce exposure to natural hazards.

The presence of disaster management plans has bolstered adaptation planning. Managers from the Risk Management Unit of the Metropolitan Office for Citizen Security, working together with the Meteorology Institute, have been following weather patterns for two decades in Quito. Through this collaboration, they became aware that severe storms were increasing the vulnerability of people living on the hillsides and slopes to flooding and landslides. In 1999, they developed the Rain Plan to prepare the city for extreme weather events and establish disaster response measures. More recently, the Risk Management Unit has been working to ensure that the city is prepared for the impacts that extreme weather events will have on the local transportation, water, electricity, and, beyond all, housing infrastructure. This includes implementing the Hillside Project, which seeks to help inhabitants living in these areas improve soil protection by reforesting fragile landscapes and preventing further housing construction through community policing.

NGOs have been an important resource for city officials. In general, NGOs in Ecuador have greater visibility and are regarded more highly by the government than is the case in many other countries in Latin America. Although many development and humanitarian aid NGOs have initiated climate adaptation campaigns, they have limited presence in Quito as most have focused their work on rural areas in the Andes and Amazon. Instead, at the present time, adaptation work generally appears to be the domain of environmental NGOs that focus on technical and scientific work. Organizations such as Fundación Natura, Ecociencia, Forum for Hydraulic Resources, SESA, the local office of The Nature Conservancy are all highly respected for their research, projects to protect fragile ecosystems around the páramos, and efforts to promote improved water management. These organizations have published a number of studies on how the páramos around Quito are affected by different climate and industrial threats. They also supported the efforts of scientists working in government agencies as well as helped to implement government environmental initiatives.

The availability of financial resources and technical assistance have advanced and sustained adaptation-related initiatives in Quito. One of these, the Environmental Fund, was created in 2005 within the Environmental Office to protect and conserve the natural resources and environmental quality of the district. At present, the Fondo Ambiental is financing dozens of projects around the district with the objective of improving the economic conditions of local populations, creating greater social cohesion, and protecting fragile areas around Quito's water basins. While some projects are implemented by the city, others are implemented by local environmental NGOs. The Fund for Water Protection (Fondo para la Protección del Agua - FONAG), created in 2000 through support from the EMAAP-Q, the Nature Conservancy, and local corporations, is another key financial resource that serves as a platform for climate adaptation. As with the Environmental Fund, projects supported by FONAG are not officially deemed as climate adaptation. However, they support related efforts since the FONAG's mission is to protect the basins used by Quito for water provision, as well as to raise awareness about the need to improve the management and conservation of water resources around the city.

Existing resources provide a foundation on which Quito is building its climate adaptation program. At the same time, new resources are being dedicated to institutionalize and implement the EQCC. As a first step, at the end of 2008, the Metropolitan Office for the Environment decided that it should create a Climate Change Unit. Since this decision has not yet been approved by the Metropolitan Council, financial resources have not been allocated and staffing is limited to two people who are responsible for implementing the EQCC. If the Unit is approved, it will work to improve the sustainability of the climate change strategy, manage available funds, coordinate the initiatives and projects of metropolitan agencies and offices, and give the strategy greater visibility. To ensure that the EQCC has support from agencies across the city, the Unit is planning to organize regular workshops and meetings with key staff from the EMAAP-Q, the Planning Office, and the Risk Management Unit. As the process moves forward, the Unit will be in charge of implementing the climate strategy and monitoring whether it is achieving its mitigation and adaptation goals.

4. COMPARATIVE ANALYSIS OF FACTORS SHAPING ADAPTATION PLANNING

The cases of Durban and Quito demonstrate that while incentives, ideas, and resources all are relevant to urban change, the specific ways in which these factors shape adaptation planning do not fully conform to the patterns predicted by prevailing theories. For instance, contemporary theories emphasize how external pressures, particularly regulations and financial incentives will motivate action (e.g., DiMaggio & Powell, 1983; Dobbin, Simmons, & Garttre, 2007). However, this was not the case in either city. Regulations pertaining to adaptation have not been established at the national level. Further, even though both cities face resource constraints, neither funding or pressures from funders shaped decisions to initiate adaptation planning. In both instances, the cities elected to pursue adaptation and then sought financial support for specific projects or worked to integrate adaptation objectives into their currently funded activities. To some extent, this approach likely reflects where these cities are on the adaptation curve. As early adapters, they are pursuing a course of action that is just gaining international recognition and that is not widely funded at the present time. Consequently, rather than serving as an incentive, funding provided support for their visions and efforts in this domain.

TABLE 1
Incentives, Ideas, and Resources Related to Adaptation Planning

	Durban	Quito
Incentives	• Protect against natural disasters • Secure development path	• Protect against natural disasters • Enhance reputation
Ideas	• Awareness of potential climate impacts • Information from international networks • Ideas from demonstration projects	• Awareness of potential climate impacts • Information from international networks • Information from domestic networks
Resources	• Government employee as champion • Formation of dedicated climate division • Strong environmental programs • Community-based adaptation initiatives • Environmental NGO engagement • Specialist input from consultants	• Public official as champion • Formation of dedicated climate division • Strong environmental programs • Capacity of municipal water corporation • Environmental NGO engagement • University research

As summarized in Table 1, rather than being influenced by external pressures, it appears that locally-determined goals and values were critical drivers of adaptation planning in both cities. One influential incentive was ensuring the safety of local populations and protecting the natural and built environments from natural disasters. Both cities were aware of projected changes in whether patterns. For Durban, this point was reinforced by severe storm and flood events. In Quito, floods and landslides that affected city services and infrastructure affirmed predictions about climate change and provided a cogent rationale for initiating adaptation planning.

Although there were similarities in the general types of incentives shaping adaptation planning in both cities, there were differences in the underlying goals motivating action. In Durban, the projected development path as delineated in the IDP structures all local action. From the start, adaptation was viewed as a means to advance sustainable development and therefore, it was seen as integral to achieving this broader set of goals. For Quito, maintaining a competitive advantage is an important goal. Climate planning was viewed as a way to enhance the city's reputation in the region as innovative, forward thinking, and politically important. It also was regarded as a way to maintain visibility and a favorable profile in the international arena.

The diffusion of international knowledge and norms, and ties to international networks, are recognized by scholars as having significant impacts on local behavior (e.g., Stone, 2004; Dobbin, Simmons, and Garttre 2007; Schreurs 2008). In contrast, adaptation planning in both cities was primarily influenced by locally-relevant, and often locally-generated, ideas and information. For instance, the impact analysis conducted in 2006 in Durban generated political and administrative interest in understanding in how the city was going to be affected by climate change and how it could respond to the predicted impacts. Membership in global networks and attendance at international conferences were important sources of ideas and information for both cities. However, rather than being influenced by global norms or best practices being advocated by representatives from the North, participation in networks and events were valued as opportunities for two-way exchange and for identifying ideas and activities that could advance local goals and priorities.

The presence of human and political resources was essential to initiating and sustaining change in both cities. Adaptation planning was catalyzed by an individual from within the government, either an employee or elected official, who was compelled by the science and served as a champion to raise awareness and initiate action. In both cases, these individuals had environmental orientations, understood the implications of the science for city management, and were able to communicate these insights to others in positions within city government. While these individuals were influential, they had different levels of success in generating short term support for climate initiatives within their cities. In Durban, adaptation planning took root early, relative to most other cities. Although the assessment sparked interest and the MCPP was established, and some Councilors immediately recognized the importance of climate impacts on the city, adaptation planning has been slow to gain widespread political support. In contrast, in Quito, Mayor Moncayo initiated informal efforts and, subsequently, Councilor Ortiz was able to mobilize support around his proposal to create an official strategy to address climate change after his presentation at the Metropolitan Council. The continued engagement and monitoring of this process by Ortiz and other councilors motivated the Environmental Office to move quickly to develop a strategy. The differences in political support seem to be associated with broad city uptake of the climate change idea in Quito while in Durban it still is a "niche" concept associated with a limited number of actors.

Resources are important for initiating a program of action, but so too is resourcefulness. Both cities faced notable capacity limitations. Rather than wait until they had additional funding or personnel, they found innovative ways to draw on and extend their capacity so that they could initiate climate planning and action. For instance, both cities were able to build on existing environmental programs, draw on networks, and find ways to link adaptation to ongoing initiatives. In addition, while the specific approaches varied in each city, both were able to engage NGOs, CBOs, consultants, and universities.

5. EARLY LESSONS FROM EARLY ADAPTERS

A number of lessons can be learned from the adaptation planning processes in Durban and Quito. In general, these experiences suggest that cities may need to develop general strategies as well as sector-based plans in order to have successful adaptation programs. Once Durban became aware of the impacts that climate change was projected to have on the city through their impact assessment, municipal staff members developed a general adaptation strategy. However, relatively quickly they discovered that they needed more concrete measures to guide action, so they now are in the process of developing more detailed planning protocols for each sector. Quito has had a detailed water plan in place for many years, but the city found that it needed to have an integrated climate action plan. As the experiences in Quito and Durban suggest, a strategy provides a general framework that can integrate citywide action and offers opportunities for public input. However, strategic plans need to be augmented with sector plans that include specific goals and implementation targets.

The cases of Durban and Quito demonstrate the importance of linking adaptation planning and implementation to city priorities and existing initiatives. While local governments generally seek to provide basic services and ensure a good quality of life for their citizens, most have limited resources. Frequently, climate change is perceived as a distant threat and is often regarded as less important, or in conflict with immediate priorities. Helping cities see how adaptation can support their goals and priorities, and how adaptation measures can be connected to ongoing activities, may be a way to facilitate planning and implementation. For instance, Durban is encountering ongoing issues related to water scarcity. While the water sector is proactive in its efforts to stabilize service provision by engaging in efforts such as repairing leaks and upgrading pipes, they do not regard these initiatives as being motivated by adaptation needs. In Quito, large areas have been set aside as green space. Although these initiatives contribute to adaptation by helping reduce the impacts of storms by slowing runoff and limiting heat island effects, they mainly are viewed as ways to beautify the city, improve the quality of life for local populations, and build tourism. As these examples suggest, there are many ongoing activities that can contribute to urban resilience. Acknowledging the presence of climate impacts and then building on and extending existing work is a way to promote adaptation in the context of departmental work routines and goals.

Efforts need to be made to ensure that cities have access to reliable information and opportunities to share experiences and ideas through local, regional, national, and international networks, seminars, and conferences. While there are abundant materials on the internet and in print, it appears that interpersonal exchange, including informal discussions of new activities and initiatives are ways that cities learn from others and extend their adaptation programs. Scientific information about climate impacts is vital, but so too is knowledge sharing around sector specific issues and climate governance more broadly. As the cases suggest, seminars and workshops within cities can be just as influential as international conferences. The import of information obtained through different types of networks and events suggests that forums for exchange should be established and participation in diverse types of climate-related events should be supported. This includes forums within cities so that information is shared across departments, as well as fostering participation in events in the regional, national, and international arenas.

The trends across both cities suggest that it is important to have a dedicated climate team that is working within a centralized office. This office needs to be appropriately staffed and funded. It also needs to have sufficient authority to enlist cooperation from upper and mid-level staff members of sector offices and to foster intergovernmental coordination and communication. Climate change frequently is assumed to be an environmental issue as individuals within the environmental sector tend to be first to make efforts to promote adaptation and initiate this work by building on existing environmental programs. While this provides an important foundation, it can lead to climate offices being situated within environmental departments. This can be problematic since environmental functions in local government frequently are weak and marginalized. The impact is that climate change is labeled “green” before there is a chance to understand its crosscutting nature and significance to development more broadly. Rather than relegate adaptation to a single sector, an alternative would be to create a Climate Protection Department within the office of the City Manager or Mayor. This would reinforce the interdepartmental character of climate impacts while demonstrating that the adaptation has status and political support.

The engagement of NGOs, CBOs, consultants, and universities can enhance municipal adaptation efforts. The cases suggest that initiation and success of adaptation planning rest on the commitment of government actors and departments. While government support is essential, cities can extend their capacity by engaging a variety of stakeholders. For instance, an environmental NGO is working collaboratively with the EMD in Durban. In addition, the city has begun to draw on its existing Ward structure to engage communities and community groups and to build their adaptation capacity. In addition to these civil society actors, Durban engaged consultants to conduct studies and assist with projects. Similar to Durban, NGO adaptation work in Quito appears to be limited to organizations with an environmental focus. For the most part, rather than working directly on projects, these NGOs have conducted research that has provided important information to governments. Quito also has relied on university scholars, centers, and programs to provide it with research in support of its initiatives.

6. CONCLUSIONS

Minimizing the impacts that climate change will have on cities and their inhabitants requires that urban municipalities make concerted efforts to protect natural systems, the built environment, and human populations. City plans and planning processes are guided by the beliefs and goals that local public officials, representatives, and communities seek to advance. More often than not, these individuals and institutions are inclined toward maintaining the status quo. However, as transitions in Durban and Quito suggest, even highly resource-constrained cities are able to alter their practices.

The cases suggest that specific types of incentives and ideas can foster institutional change and promote adaptation planning in cities. Dedicated regulations and financial incentives are not yet influential in the adaptation arena and therefore, do not shape the activities of early adapters. Instead, these cities tend to be driven by their existing goals and priorities and influenced by the recognition that taking action in the short term is likely to ensure the viability of their cities in the long term. With respect to ideas, awareness of local vulnerabilities stemming from scientific information and assessments had a notable influence on climate decisions and actions. More generally, both cities benefited from personal interactions and participation in diverse forums as these fostered an exchange of information and ideas that generated locally-relevant insights.

The findings demonstrate the ways in which capacity serves as a complement to incentives and ideas in the adoption and mainstreaming of new urban initiatives. A critical resource that emerged in both cases was the presence of a local champion. These individuals can help raise awareness of the risks and importance of adaptation planning, identify ways to link adaptation to existing programs, and seize new opportunities that emerge in order to extend and mainstream adaptation efforts. Political support also emerged as an important resource. The support of public officials in both cities determined whether adaptation was viewed as a legitimate issue and affected the rate at which planning and implementation took place. Resources are important, but so too is resourcefulness. Efforts in both cities to link adaptation to ongoing initiatives and to engage the support of diverse stakeholders provided a means for extending capacity and creating a foundation for adaptation planning.

The trends and accomplishments in Durban and Quito provide insight into steps cities can take to initiate and sustain climate adaptation programs. First, while general strategies and broad guidelines are central to establishing a vision, action is predicated on the creation of sector-specific adaption plans that include goals and intermediate targets. Second, the mainstreaming of climate adaptation may be most readily achieved when initiatives are linked to local priorities and ongoing activities. Third, it is essential to ensure that there are multiple ways for cities to gain access to reliable information. This includes locally-relevant scientific information about risks as well as information on pertinent adaptation measures. Fourth, cities need opportunities to share experiences and ideas through local, regional, national, and international networks, seminars, and conferences. Fifth, cities should be encouraged to establish climate offices that are not affiliated with a specific department or sector. These offices also need to be given adequate visibility and resources so that they can initiate and implement change. Finally, while local governments need to make a commitment to adaptation and work to coordinate intergovernmental efforts, they should extend their capacity by engaging nongovernmental stakeholders, including NGOs, CBOs, consultants, and universities.

The findings presented in this paper are based on the activities of two cities with similar administrative structures. It is likely that as more cities pursue adaptation planning, and we have opportunities for comparison across those with diverse forms of administration and management, we will uncover new trends and experiences in the adaptation planning process. In addition, the two cities studied here had relatively limited engagement with NGOs and moderate levels of institutional and financial capacity. Cities with alternative civil society relationships or different levels of capacity may follow different trajectories as different drivers may take on greater significance in these settings. Finally, it is important to acknowledge that as the adaptation context changes, and national governments develop regulations and dedicated adaptation funds and funder requirements emerge, late adapters will encounter different circumstances than the early adapters described in this paper.

Prevailing theories emphasize the ways in which external pressures and the diffusion of global knowledge and norms drive local change. However, the trends in Durban and Quito suggest that for early adapters, local change is shaped by an ability to link new initiatives to local priorities, to identify and generate locally-relevant knowledge, and to build upon ongoing routines and existing programs. These patterns not only offer a counterpoint to the dominant theories, but offer practical lessons for policymakers and other cities seeking to engage in adaptation planning and implementation.

References

Adger, W. Neil, Jouni Paavola, Saleemul Huq, and M. J. Mace. 2003. *Fairness in Adaptation to Climate Change*. Cambridge. MA: MIT Press.

Birkland, Thomas A. 1997. *After Disaster: Agenda Setting, Public Policy, and Focusing Events*. Washington, DC: Georgetown University Press.

Boli, John and George N. Thomas. 1999. *Constructing World Culture: International Non-Governmental Organizations since 1875*. Stanford, CA: Stanford University Press.

Burch, Sarah and John Robinson. 2007. "A Framework for Explaining the Links between Capacity and Action in Response to Global Climate Change." *Climate Policy* 7 (4): 304–16.

Clemens, Elisabeth S. and James M. Cook. 1999. "Politics and Institutionalism: Explaining Durability and Change." *Annual Review of Sociology* 25: 441–66.

Comité Nacional Sobre el Clima. 2001. *Primera Comunicación Nacional sobre Cambio Climático.* Ministry of the Environment: Quito.

DEAT/UNDP. 2008. "National Capacity Self Assessment: Draft Thematic Profile for Climate Change." Unpublished report.

Diederichs, Nicci. 2008. "Community Reforestation Project Proposal." Prepared for eThekwini Municipality.

DiMaggio, Paul and Walter W. Powell. 1983. "The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields." *American Sociological Review* 48: 147–60.

Dirección Metropolitana Ambiental y Fondo Ambiental. 2008. *Quito Strategy for Climate Change*. Quito: DMQ.

Dobbin, Frank, Beth Simmons, and Geoffrey Garrett. 2007. "The Global Diffusion of Public Policies: Social Construction, Coercion, Competition, or Learning?" *Annual Review of Sociology* 33: 449–72.

Dumas, Juan. 2007. "Necesidades de Adaptación y Mitigación para Enfrentar el Cambio Climático en Ecuador."*Ambiente y Desarrollo,* 23 (2): 48–9.

El Universo. 2006. *Un muerto en Quito por el invierno.* http://archivo.eluniverso.com/2006/04/11/0001/12/7338256673524D6481A9825F6907BE93.aspx.[Accessed April 11, 2006].

ERM (Environmental Resources Management), 2008. "Plans for the Health and Water Sectors of eThekwini Municipality Proposal." Report prepared for eThekwini Municipality.

Few, Roger, Katrina Brown, and Emma L. Tompkins. 2007. "Public Participation and Climate Change Adaptation: Avoiding the Illusion of Inclusion." *Climate Policy* 7: 46–59.

Francou, Bernard, Edson Ramirez, Bolívar Caceres, and Javier Mendoza. 2000. "Glacier Evolution in the Tropical Andes during the Last Decades of the 20th Century: Chacaltaya, Bolivia, and Antizana, Ecuador." *Ambio,* 29: 416–22.

Gobierno del Ecuador, Programa de las Naciones Unidas para el Desarrollo, Ministerio de Ambiente del Ecuador. 2008. *Adaptation to Climate Change through an Effective Governance of Water in Ecuador*. Ministry of the Environment: Quito.

Golder Associates. 2008. "Community-Based Adaptation Programmes in Durban: Inception Report." Report prepared for eThekwini Municipality.

Granberg, Mikael and Ingemar Elander. 2007. "Local Governance and Climate Change: Reflections on the Swedish Experience." *Local Environment,* 12(5): 537–48.

Greenstone, Clive. 2008. "Redressing the Vertical Urban Layer and the Notion of Green Rooftops Proposal." Report prepared for eThekwini Municipality.

Greenwood, Royston, Roy Suddaby, and C. R. Hinings. 2002. "Theorizing Change: The Role of Professional Associations in the Transformation of Institutionalized Fields." *Academy of Management Journal* 45 (1): 58–80.

Gutner, Tamar L. 2002. *Banking on the Environment: Multilateral Development Banks and their Performance in Central and Eastern Europe*. Cambridge, MA: MIT Press.

Hicks, Robert L. Bradley C. Parks, J. Timmons Roberts, and Michael J. Tierney. 2008. *Greening Aid?: Understanding the Environmental Impact of Development Assistance*. Oxford: Oxford University Press.

IPCC. 2007. "Climate Change 2007: Impacts, Adaptation and Vulnerability." Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press, UK.

Jasanoff, Sheila. 2005. *Design on Nature*. Oxford: Oxford University Press.

Jones, Roger and Atiq Rahman. 2007. "Community-Based Adaptation." *Tiempo*, 64: 17–9.

Kingdon, John. 1995. *Agendas, Alternatives, and Public Policies*. New York: HarperCollins.

Kirshen, Paul, Kelly Knee, and Matthias Ruth. 2008. "Climate Change and Coastal Flooding in Metro Boston: Impacts and Adaptation Strategies." *Climatic Change* 90: 453–73.

Maisinchi, L., et al. 2005. *Glaciares del Ecuador: Antisana y Carihuayrazo*, Informe del año 2004. Quito: IRD-INAMHI-EMAAP-Q.

Mukheibir, Pierre and Gina Ziervogel. 2007. "Developing a Municipal Adaptation Plan (MAP) for Climate Change: The City of Cape Town." *Environment & Urbanization,* 19 (1): 143–58.

Princen, Thomas. 1994. "NGOs: Creating a Niche in Environmental Diplomacy." In *Environmental NGOs in World Politics: Linking the Local and the Global*, ed. T. Princen and M. Finger., 29–47. London: Routledge.

Reeve, Kara, Isabelle Anguelovski, and JoAnn Carmin. 2008. "Climate Change Campaigns of Transnational NGOs: Report of Survey Findings." Report prepared for Friends of the Earth International and Oxfam Great Britain. Cambridge, MA: MIT Department of Urban Studies and Planning.

Roberts, Debra. 2008. "Thinking Globally, Acting Locally: Institutionalizing Climate Change at the Local Government Level in Durban, South Africa." *Environment & Urbanization* 20 (2): 521–37.

Roberts, J. Timmons and Bradley C. Parks. 2007. *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy*. Cambridge, MA: MIT Press.

Sabates-Wheeler, Rachel, Tom Mitchell and Frank Ellis. 2008. "Avoiding Repetition: Time for CBA to Engage with the Livelihoods Literature?" *IDS Bulletin* 39 (4): 53–9.

Sánchez, Pilar. 2006. *Boletin de Prensa.* Comunicacion Social CBDMQ. Quito. http://www.bomberosquito.gov.ec/boletines/2006/10-11%20MAYOA.pdf.

Schreurs, Miranda A. 2008. "From the Bottom Up: Local and Subnational Climate Change Politics." *The Journal of Environment & Development* 17 (4): 343–55.

Scott, W. Richard. 1995. *Institutions and Organizations*. Thousand Oaks, CA: Sage.

Semiond H., et al. 1998. *El Glaciar 15 del Antisana, Investigaciones Glaciológicas 1994-1997*. Quito: Instituto IRD.

Smit, Barry, Ian Burton, Richard J. T. Klein, and J. Wandel. 2000. "An Anatomy of Adaptation to Climate Change and Variability." *Climatic Change* 45: 223–51.

Stone, Diane. 2004. "Transfer Agents and Global Networks in the 'Transnationalisation' of Policy," *Journal of European Public Policy* 11 (3): 545–66.

Strang David and John W. Meyer. 1993. "Institutional Conditions for Diffusion." *Theory & Society* 22 (4): 487–511.

Tellum, Ian. 2007. "Adaptation Targets." *Tiempo* 64: 14–6.

Tol, Richard S. J., Thomas E. Downing, Onno J. Kuik, and Joel B. Smith. 2004. "Distributional Aspects of Climate Change Impacts." *Global Environmental Change* 14 (3): 259–72.

van Aalsta, Maarten K., Terry Cannon, and Ian Burton. 2008. "Community Level Adaptation to Climate Change: The Potential Role of Participatory Community Risk Assessment. *Global Environmental Change* 18 (1): 165–79.

World Bank. 2006. *Adapting to Climate Change: Activities, Lessons Learned, Work in Progress and Recommendations for Latin America and the Caribbean Region*. Washington, DC: World Bank.

________. 2008. *Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Climate Change Impacts and Strengthening Disaster Risk Management in East Asian Cities*. Washington, DC: World Bank.

________. 2008. *Exploring Urban Growth Management Insights from Three Cities*. Washington, DC: World Bank.

Zahran, Sammy, Himanshu Grover, Samuel D. Brody, and Arnold Vedlitz. 2008b. "Vulnerability and Capacity: Explaining Local Commitment to Climate-Change Policy." *Environment and Planning C* 26: 544–62.

Zahran, Sammy, Samuel D Brody, Arnold Vedlitz, Himanshu Grover, and Caitlyn Miller. 2008a. "Risk, Stress, and Capacity: Explaining Metropolitan Commitment to Climate Protection." *Urban Affairs Review* 43 (4): 447–74.

CHAPTER 18

Climate Change and the Resilience of New Orleans: the Adaptation of Deltaic Urban Form

Armando Carbonell, Douglas J. Meffert*

1 INTRODUCTION

Using New Orleans, Louisiana, USA as the departure point, this paper discusses emergent trends of climate change and hurricanes, along with policies and practice representing adaptive land use, mitigation, and governance. The role of urban form in adapting to and mitigating climate change will be addressed, including an emphasis on natural wetland and water "ecostructures". The New Orleans case study offers information that can inform international sites, particularly historic, vulnerable port delta cities.

1.1 Coastal Louisiana and New Orleans

For most of the 20th century, New Orleans was sustained paradoxically by enhanced drainage of its delta subsurface along with increased efforts on managing land and water at its perimeter and regional environs (e.g., levees and floodwalls). At the same time, coastal Louisiana was experiencing one of the highest coastal wetland loss rates in the world due to the combined and exacerbating effects of seasonal sediment deprivation from the Mississippi River levees, natural compaction and subsidence, subsidence from oil and gas extraction, sea level rise, and nutria consumption of native wetland vegetation.

*Corresponding author: dmeffert@audubon.org

The continued loss of wetlands and increased vulnerability of New Orleans was widely discussed and debated among many scientists, engineers, and policy-makers for decades before Hurricane Katrina. The immensity of the problem was revisited in the early 21st century when Hurricanes Katrina and Rita resulted in approximately 217 square miles of wetland conversion (loss) to water statewide, 117 square miles of which was due to Hurricane Katrina (CPRA 2007). Around metropolitan New Orleans, where the wetlands have historically formed a critical storm surge buffer, the loss of coastal marshes in that particular year was so great that it represented about 50 years of projected wetland loss.

Much has been written and debated about how and where New Orleans residents should repopulate. Many of these discussions recommend rebuilding — or relocating — with the expectation of future flooding, clustering populations in areas safest from natural disaster, and enhancing natural processes to the greatest extent possible.

The destruction and increased vulnerability of wetlands has reached a critical level worldwide. Over the last 200 years, wetlands in the United States have been drained, dredged, filled, leveled, and flooded for urban, agricultural, and residential development. In consequence, the 220 million acres of wetlands that once existed in the contiguous U.S. have been reduced to about 103 million acres (Watzin and Gosslink 1992). These losses are important because wetlands are among the most highly productive ecosystems on Earth, and provide a variety of economically important products and services (Costanza and Farber 1985). Scientists have recognized the need to restore or replace lost wetlands. Until recently, most wetland restoration efforts were relatively small, but a few large-scale restoration efforts (50,000 acres and larger) have been implemented.

Nowhere in the United States are wetland losses greater than in Louisiana. Louisiana's coastal zone was formed by sediments deposited during a series of 16 major Mississippi River deltaic episodes over the past 7,000 years, creating a region of coastal wetlands covering 3.3 million acres of the state (Cowan and Turner 1988; Turner and Rao 1990; Good et al. 1995). These wetlands represent 30% of coastal wetlands in the contiguous U.S. but are experiencing 90% of coastal wetland loss (CPRA 2007; LCWCRTF 1993; Dahl 2000). The causes of this wetland loss include cumulative natural and human-induced impacts (LCWCRTF 1993; Boesch 1982; Mendelssohn 1983; Titus 1986; Turner and Cahoon 1987; Day and Templet 1989; Duffy and Clark 1989). Beginning in the 18th century and accelerating after the record flood of 1927, the construction of artificial levee systems has eliminated the overbank contribution of sediment of flood flows from the Mississippi River to Southeastern Louisiana (Turner and Rao 1990; Kesel 1989). In addition, during the 19th and 20th centuries, navigation channel dredging, oil and gas exploration and production, land reclamation, and the construction of commercial and industrial facilities further damaged the coastal region in terms of primary and secondary wetland losses. These activities have caused reductions in new accretion and freshwater inflow, led to increases in saltwater intrusion and wave energies on a fragile interior marsh substrate, and destroyed emergent vegetation which would otherwise bind sediments and produce organic matter. By 2050 it is projected that Louisiana will have lost more than one million acres of coastal wetlands, an area larger than the State of Delaware (LCWCRTF 1993; Meffert et al. 1997). In addition, the Gulf of Mexico will continue to advance inland as much as 33 miles during this period, transforming previously productive wetlands into open water and leaving major towns and cities, such as New Orleans and Houma, exposed to open marine forces of the Gulf of Mexico (CPRA 2007; Titus 1986; Lopez 2005; NCMGCEC 2006).

If the coastal land loss trend continues, Louisiana will sustain major economic and social losses including: (1) damages, control costs, and insurance claims from floods and hurricanes; (2) oil and gas infrastructure; (3) private land and residences; (4) commercial seafood production; (5) commercial hunting and trapping; (6) recreational hunting and fishing; (7) shipping; (8) channel and river maintenance; (9) drinking water; (10) water quality improvements; and (11) employment. When one accounts for functional values, infrastructural investments, and biologic productivity, Louisiana's coastal wetlands value exceeds $100 billion dollars (CPRA 2007; LCWCRTF 1993). These resources provide more fishery landings than any other coterminous U.S. state (CPRA 2007; USDOC 1994), the largest fur harvest in the U.S. (CPRA 2007; Coreil 1994), 21% of the nation's natural gas supply (CPRA 2007; LCWCRTF 1993), and protection for waterborne cargoes representing 25% of the nation's total exported commodities (CPRA 2007). Because many of these benefits and services are of national interest, the entire country, not just Louisiana, stands to lose a vast economic resource.

1.2 Climate Change Implications

With expectations of climate change-related relative sea level rise of 3-10 mm per year in the next 50 years (Törnqvist et al. 2008), the vulnerability of the New Orleans metropolitan area and the rest of coastal Louisiana will only be exacerbated, leading to an increased need for people to reside in the least vulnerable zones, whenever possible. When one accounts for both subsidence endemic to Louisiana's deltaic coast and global sea level rise, recent estimates of relative sea level rise project the Gulf of Mexico will be anywhere between 2-6 feet higher in the next century (Törnqvist et al. 2008; Day and Giosan 2008; Marshall 2008).

Despite these recent and dire predictions, with the exception of populated areas in New Orleans that are below sea level, urban and rural populations of Louisiana's coastal zone have long existed with the natural flooding propensity of the region — with many small towns in the deltaic plain, in particular, prioritizing residential land use along the limited levee areas of bayous and former distributaries of the Mississippi River, so that they can remain above sea level and minimize risks associated with flooding and storm surge. The problem now is that many of the small rural towns in coastal Louisiana that have been able to sustain themselves near sea level for the past century will succumb to sea level rise during the next century and, those that remain above sea level but on the ridges of the former Mississippi River distributaries will no longer have the wetland buffers that have historically protected them from diurnal fluctuations of sea level, intermittent storms, and less frequent but increasingly catastrophic hurricane/tropical storm surges. For many of these towns, residential relocations are inevitable. Given these relocations, the State has an opportunity to re-examine future land use priorities in the delta plan and implement both structural and non-structural interventions that will maximize the productivity of these systems while minimizing economic and cultural losses and social justice dilemmas.

2 THE ECOSTRUCTURE HYPOTHESIS

Specific crosscutting research questions addressed in this paper (adapted from ICLEI — Local Governments for Sustainability Urban Biosphere Programme) are:

1. What are the main ecological drivers of change at the regional and local scales that impact urban resilience following a disaster and adaptation to climate change?
2. What is the role of ecosystem services and land use transformation in promoting human well-being and safety, reducing vulnerability, and enhancing adaptation and mitigation to climate change?
3. What are the spatial, jurisdictional, and temporal scales required to ensure sustainable governance of urban systems?

For purposes of this research, the definitions of adaptation and mitigation are consistent with the Intergovernmental Panel on Climate Change (IPCC) Fourth Working Group (IPCC 2007):

Adaptation is defined as "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g., anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc."

Mitigation is defined as "technological change and substitution that reduces inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce Green House Gas (GHG) emissions and enhance sinks."

The hypothesis is that restoring and enhancing ecosystem services (i.e., "ecostructure") of urban systems in the context of regional natural systems with appropriate jurisdictional oversight and local governance increases the ability of these urban systems to adapt to and mitigate the effects of climate change.

3 METHODOLOGY

The methodology chosen is a synthetic assessment of large-scale ecosystem restoration, flood protection, jurisdictional advocacy and oversight, and land policies that promote climate change adaptation and mitigation for New Orleans and its contextual regional ecosystem. Given the nascent nature of New Orleans' recovery from Hurricane Katrina and coastal master plan implementation, primary sources of information are peer-reviewed when available, or from journalistic accounts when peer-reviewed or government documents are not available.

Since many of the most significant indicators of actual implementation of large-scale adaptation and mitigation measures are not yet available, a quantitative model is not proposed in this paper for linking social and governmental actions with resultant adaptation and mitigation outcomes. Rather, a qualitative review of peer-reviewed, popular, and government reports regarding urban and coastal restoration and planning are synthesized with a particular emphasis on relevance to climate change adaptation and mitigation. For example, while the Wetland Value Assessment (WVA) methodology behind selection of priority wetland restoration projects is well established (providing a common metric of average annualized habitat units (AAHUs), these assessments are prospective in nature for an average project "lifetime" of twenty years of accrued benefits (LCWCRTF 1993; Meffert et al. 1997). Furthermore, as discussed later in this paper, the projects that have been determined to have the greatest benefits in terms of large-scale adaptation and mitigation have not yet been implemented due to lack of land policy resolution and funding, so there is no available information yet on the efficacy of these projects. It is possible, however, to perform a qualitative review of cumulative expected outcomes.

This paper thus provides a qualitative review on the adaptation of urban form in New Orleans to date, with a particular focus on ecostructural approaches, and extrapolates this information to recommended future land use and other practices that can be applied to cities with similar conditions internationally.

4 ECOSYSTEM AND POLICY ADAPTATION

4.1 Ecological/Coastal and Urban Form Comparisons

Just as ecologists examine ecological systems in terms of their carrying capacity of keystone species, one can examine urban and other coastal human settlements in terms of their residential carrying capacity. So how do prevailing gradual environmental trends (e.g., relative sea level rise and coastal wetland loss) and acute threats (e.g., hurricanes and flooding) impact urban and rural coastal carrying capacity in Louisiana? The pre-Katrina trend was already one of dramatic historical wetland loss since these regions are the vestiges of former Mississippi River delta lobes and are thus subject to the natural compaction and deterioration of these habitats which has been exacerbated by relative sea level rise and other anthropogenic interventions (e.g., leveeing the Mississippi River, oil and gas exploration, wetland conversions to agriculture and other development).

With regard to the first crosscutting research question described earlier in this paper, the main ecological driver of enhanced resilience on both regional and local scales is restoration and preservation of coastal wetland habitats. Current plans are to restore as much of this marsh as quickly as possible with a combination of adaptation and mitigation measures, including restoration of natural delta building, marsh creation from use of dredged material, water control structures, and hard structures e.g., dikes and levees (CPRA 2007; LRA 2007; CPRA 2009). The most interior marshes have been prioritized for conservation and restoration because of the ecological benefits (e.g., habitat for fisheries, support of indigenous plant and animal life) and storm surge protection they provide to the more densely populated areas, including New Orleans, and oil and gas exploration and transportation infrastructure. The most prominent occupied landscape feature currently identified for abandonment is the modern (aka "bird's foot") delta of the Mississippi River. Plans call for this land/marsh material to be utilized for restoration/re-creation of marsh that is located proximate to more densely populated areas.

Campanella (2007) has assessed vacant parcels and lots in Orleans parish in order to calculate the potential incremental increase in residential carrying capacity of areas above sea level in New Orleans (beyond those properties already identified as blighted, which are under the jurisdiction of the New Orleans Redevelopment Authority). By this estimate, New Orleans could accommodate roughly 300,000 residents above sea level (in 1960 this area held a peak population of 306,000), which is 115,000 more than the 185,000 residing above sea level in 2006.

Given the knowledge that deltaic cities like New Orleans will likely experience 3-10mm per year of relative sea level rise over the next 50 years (Törnqvist et al. 2008), residential development should be the priority use for higher elevations, with lower elevations reserved to support fisheries, storm surge protection, and other ecosystem services. If one is to prioritize areas 1 foot above sea level or higher for residential occupation, for example, available space is limited in the deltaic plain of coastal Louisiana to primarily levees and ridges along rivers, bayous and former distributaries of the Mississippi River . While a larger regional levee system in south Louisiana is proposed to provide 100-year protection for about 120,000 rural residents in Louisiana coastal areas (Walsh 2007), thousands of residents are left outside of protection systems. For the Delta lobe (e.g., Boothville-Venice) residents, these lands will ultimately be abandoned, with marsh creation (e.g., through beneficial use of dredge material) being prioritized for degraded marsh in Barataria, Terrebonne, and Breton Sound basins, in particular. So far, relocation is based primarily on voluntary actions of residents and this must be re-examined carefully in terms of design, planning, and policy with an eye to both vulnerability and litigation exposure.

4.2 Ecosystem and Land Use Adaptation to Climate Change and Disaster: Chronic Perturbation v. System "Shocks"

Of necessity, human populations worldwide will continue to occupy urban areas that are vulnerable to the impacts of slow variables (e.g., sea level rise, periodic flooding, etc.) and threshold events (e.g., natural disasters) – some of which will be severe. As a deltaic city, New Orleans has always been situated in a dynamic landscape. After achieving its peak urban population in the early 1960's, in the 40 years before Hurricane Katrina, New Orleans was experiencing trends in multiple slow variables. These natural and socioeconomic indicators, including rising seas, compacting deltaic landscape, population decline, suburban sprawl in below sea level areas, coastal wetland loss, and economic decline (Campanella, Etheridge and Meffert 2004), combined to make the city increasingly vulnerable. In terms of most of these indicators, Hurricane Katrina provided a shock to the New Orleans urban ecosystem that advanced its state half a century into what its future would have been had that storm, or a similar shock, not struck the city during that period. Thus, New Orleans provides valuable clues for strategic planning of vulnerable deltaic cities worldwide.

The Gulf of Mexico of the United States has an ongoing history of natural disasters. A major hurricane has hit the Gulf Coast every year since 1994 with 26 named storms and 14 hurricanes in 2005 (NCMGCEC 2006). One of the reasons that Hurricane Katrina caused so much damage is that more than 10 million people currently live in coastal counties and parishes along the Gulf of Mexico — 3.5 times the population that lived in these counties in the 1950's (NCMGECEC 2006). Since Hurricane Katrina, numerous articles and reports have been published that mesh the theoretical underpinnings of coastal science, engineering, architecture, landscape architecture, and urban planning and design, with land use and other germane coastal policies to provide recommendations for future planning of the urban/rural form of New Orleans and its surrounding deltaic landscape (CPRA 2007; LRA 2007; Laska and Morrow 2006; Lopez 2007; Costanza, Mitsch and Day 2006; Blakely 2007; Rodiek 2007; Meffert 2008; Törnqvist and Meffert 2008). Most of these articles emphasize both adaptation and mitigation, recognizing that adaptive measures are necessary given the rapid rate of relative sea level rise and increased salinization of freshwater and brackish coastal marsh habitats. In general, recommendations include maximizing incorporation of natural ecostructural processes in community-based planning and design and minimizing deleterious environmental impacts of built infrastructure elements. While specific recommendations vary among publications, general concepts include:

1. Work with natural hydrology and propensity for flooding whenever possible and encourage a) building on higher ground with increased residential densities in these areas and b) promoting decreased residential densities in lower ground and/or floodable structures in these areas;

2. Restore natural landscapes (e.g., gradual boundaries/topography between deepwater systems and uplands) with natural processes (e.g., Mississippi River diversions) whenever possible for maximum provision of ecosystem services including storm surge and infrastructure protection;

3. Implement flood control, disaster preparedness, and landscape interventions on a neighborhood scale in existing urbanized areas and primary transportation corridors (e.g., terraces; polders; drainage enhancements, including bayous, canals and permeable surfaces);

4. Use sustainable architectural practices (e.g., renewable and efficient energy, decreased flooding propensity, materials reuse, etc.) for both renovation of existing structures and construction of new structures; and

5. Maximize community participation and restore social capital (e.g., diversity, environmental justice, and social networks) at every phase of planning, design, and implementation.

With regard to the second crosscutting research question described earlier in this paper, one can examine New Orleans urban and contextual natural habitats in terms of the ecosystem services they provide and, thus, aid prioritization of the interventions described above. Cumulatively, these interventions will increase human well-being and safety, reduce vulnerability, and enhance adaptation and mitigation to climate change. Current Tulane University CBR social-ecological research in New Orleans, for example, is testing, forensically and prospectively, whether human interventions in post-Katrina New Orleans have altered the ability of this urban and surrounding coastal ecosystem to provide for ecosystem services. The habitats of interest are the urban forest; developed residential, commercial, and public space; and other built and natural forms as they have existed historically through development patterns and in terms of prospective plantings and other future built and natural interventions. Some of the primary core services endemic to the New Orleans urban/coastal system include:

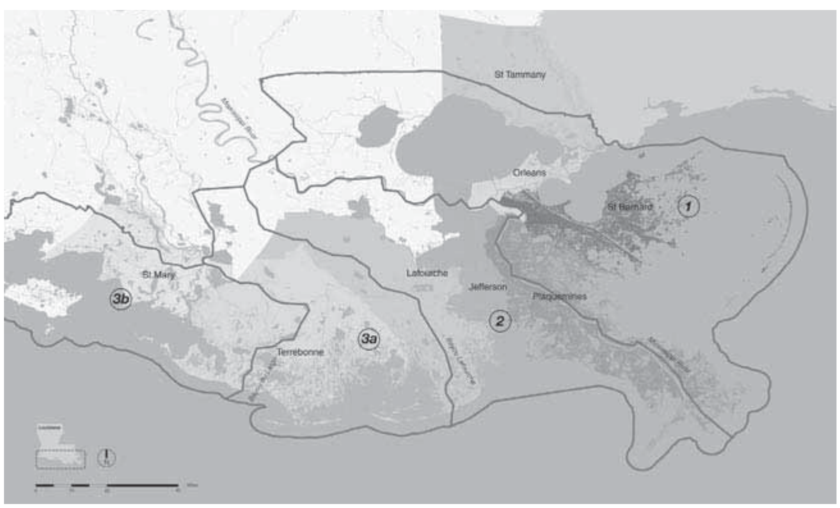
1. Provisioning services:
   a. Foods (e.g., through urban farms)
   b. Energy (e.g., biofuel production in underdeveloped formerly urban flood-prone regions)
   c. Passive stormwater runoff/infiltration (e.g., vegetative interventions/landscape architecture)
   d. Storm surge protection (e.g., from coastal wetland and barrier island habitats)
2. Regulating services:
   a. Carbon sequestration and climate regulation (e.g., urban heat island effect)
   b. Nutrient dispersal (e.g., from fertilizers utilized in the Mississippi River watershed)
3. Supporting services, including waste/chemical decomposition/detoxification (e.g., natural attenuation, phytoremediation)
4. Cultural services, including recreation and ecotourism
5. Preserving services, including genetic and species diversity of flora and fauna.

Direct and indirect feedback loops for selected indicators link up with changes in human interventions that, in turn, relate to local and political perceptions and support for these services. Services can be evaluated in terms of their ability to provide economic resources that benefit the social network of New Orleans' neighborhoods. By addressing the environmental, economic, and social networks of New Orleans, key indicators of sustainability are addressed.

4.3 Scale Mismatches in Social-Ecological Planning and Land Use Governance

With regard to the third crosscutting research question described earlier in this paper, the sustainable governance of the urbanized New Orleans metropolitan region must rely on both hard structures (e.g., levees and floodwalls) surrounding the city and the multi-parish enhancement of natural wetland habitats (e.g., through natural delta building) on a multi-decadal temporal scale. Systematic planning interventions in coastal Louisiana are complicated by mismatches between the natural boundaries of the problem at hand and those of the jurisdictions having the requisite regulatory authority or planning capacity. Figure 1 shows four of the five coastal ecosystem-based planning units (based on combinations of major watersheds/basins) overlaid on parish-governed jurisdictional boundaries (delineated by different colors of adjacent parishes). Jurisdictional mismatches exist because settlement (and subsequent local governance) in coastal Louisiana tends to straddle the high ground on coastal Louisiana bayou and river levees, while the CPRA hydrologic-based planning units are often demarcated by these same waterways – a condition counterintuitive to most water-shed based planning in areas with greater vertical topography.

FIGURE 1
Planning Units in Southeast Louisiana of the State's Coastal Protection and Restoration Authority Master Plan (outlined with solid lines).



Each unit includes one or more of the 9 major hydrologic basins in coastal Louisiana with Units One, Two, Three-A, and Three-B being delineated by the Mississippi River, Bayou Lafourche, and Bayou du Large (graphic by Jonathan Tate)

In this case, New Orleans as a municipal land use authority has planning and regulatory jurisdiction over only a small fraction of the pertinent area. The official regional planning commission created by the Louisiana legislature for the five parishes around New Orleans is a policy body without regulatory authority and also falls short in terms of geographic coverage relative to the larger coastal system implicated in planning for coastal ecosystem planning units One and Two (Figure 1). Agencies of the state and federal government are positioned to maintain and protect the larger system and regulate uses that impact coastal waters and wetlands, but may not have the mandate or political will to intervene in land use matters involving private property. These agencies include the Louisiana Office of Coastal Protection and Restoration (OCPR), Louisiana Recovery Agency, Federal Emergency Management Agency (FEMA), the U.S. Environmental Protection Agency, and the U.S. Army Corps of Engineers.

The foundation for examination of land use priorities in the New Orleans metropolitan area includes the flood advisories established by the Federal Emergency Management Agency (FEMA) after Hurricane Katrina, the proposed resettlement and land use proposals developed through the Unified New Orleans Plan (UNOP) and other relevant urban/regional plans, the recent investments through the Louisiana Recovery Authority in targeted reinvestment areas established by New Orleans' Office of Recovery and Development Administration (ORDA), the Comprehensive Master Plan for New Orleans currently under development (NOLA 2009), and other recommended flood risk adaptation activities (e.g., land swaps and voluntary structural elevations).

Regarding the New Orleans-specific documentation above, Goody Clancy (Boston, MA) was contracted by the City of New Orleans to develop a Comprehensive Master Plan (CMP) and Comprehensive Zoning Ordinance (CZO) that, if adopted, would have the force of law. As of the summer of 2010, the final CMP had been submitted to the City Planning Commission and CZO public meetings and development were in progress. Guiding principles and key features of the plan are summarized in Table 1. This planning process has also established a Sustainable Systems Working Group (SSWG) with a research and community outreach process completed in the summer of 2009. "Sustainable" recommendations in the Master Plan will contain the following elements (GCA 2008):

1. Community Facilities and Services
    a. Major components of non-transportation-related infrastructure, including water and sewer, electric, gas, and waste disposal

   b. Location, typology and characteristics of key community facilities, including schools, libraries, community centers, health clinics, police, fire, courts, and criminal justices

2. Transportation, including all roads, bridges, public transit, pedestrian amenities, bicycle, port, and airport infrastructure and systems.
3. Broad aspects of sustainability, environmental quality, and "resilience" as they relate, in particular, to green design, energy efficiency, flood protection, storm water management, hazard mitigation/emergency preparedness, and coastal restoration.

The CMP includes a general recommendation that the City of New Orleans create a "climate plan" that addresses how the city should respond to global warming (NOLA 2009). Adaptation and mitigation measures recommended within the next five years to respond to changing global weather patterns include preserving wetlands inside and outside the City's levee system to reduce neighborhood flooding and elevating houses above projected 500-year flood levels (generally three to six feet) following the anticipated 2011 completion of current levee reconstruction efforts. This working group recognizes that the future safety and resilience of New Orleans will depend on "multiple lines of defense" from storm surge and relative sea level rise (Lopez 2005) (Figure 2). This strategy includes coastal wetlands and barriers, levees and pumps, internal drainage improvements, and land use planning and regulation.

FIGURE 2
Multiple lines of defense concept (adapted from graphic produced by the Lake Pontchartrain Basin Foundation, from the CPRA Master Plan)

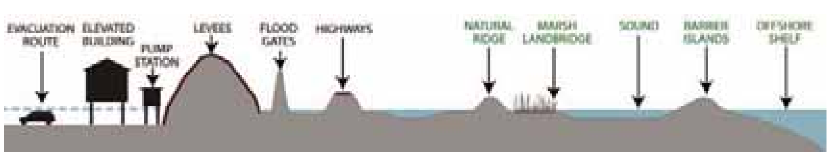


TABLE 1
Guiding Principles and Key Features of the Draft New Orleans Master Plan

Guiding Principles	Master Plan Key Features
• The future of New Orleans must be shaped by an honestly optimistic assessment assessment of its risks and opportunities. • Geography and water shape value and culture as well as drive risk. • New Orleans cannot survive as a viable community if it must evacuate frequently • A 1-in-100 year level of flood protection is essential but not adequate and is less than the City ad the Nation were committed to prior to Hurricane Katrina • The levees, pumps, and wetlands the City currently relies on are all that can be expected for the foreseeable future. • The State Master Plan and Corps of Engineers plans are not a substitute for effective action at the City since the authorization, funding and construction process for bold and effective action on next generation storm protection, coastal restoration, and climate change will be measured in decades – time the City does not have. • New Orleans can increase its near term protection and resilience by how it chooses to live with its levees, pumps, and wetlands. • No part of the City is immune from risk, though risks are not uniform across the City. Plan for water, not against it. • No part of the City should be left out of its recovery and redevelopment, but the timing and nature of recovery and redevelopment does and will vary. • It is not possible to immunize the City from risk; we must make it resilient to risk.	• A 1-in-500 year minimum level of protection from storms • A city that does not have to evacuate (except under extraordinary circumstances) • A city planning for current risks and future risks — specifically those associated with rising seas • A city that views water as an asset • Land use and water management practices that reduce risk, enhance land values and increase resilience to water, storms and other environmental hazards • Plan for, and reduce, subsidence at the city level. • Plan for, and manage, interior hydrology and storm water to reduce flooding risk. • Encourage regional cooperation and planning. • Support and advocate for improvements to long range storm protection system • Support and advocate for coastal conservation and restoration at the State and federal levels. • Support for and advocate for effective responses to rising seas and climate change. • Encourage residents to “build smart”. • Harden essential infrastructure against wind and water risk. • Community involvement — shared responsibility, collective benefit • Develop “smart evacuation” options (e.g., evacuate to locations within a community when appropriate) and accommodate evacuees when they return.

While the Master Plan/Comprehensive Zoning Ordinance (CZO) project provides an opportunity to include this approach to resilience in the vision for New Orleans future, the structural and non-structural land use provisions needed for most of this lie outside the jurisdictional boundaries of Orleans parish and are subject to a fragmented and uncoordinated land use planning and governance structure for implementation.. The recent escalating costs of restoration and levee protection, along with the decline in the price of domestic oil and gas revenue from Louisiana (which reduces the State's ability to generate matching revenue for coastal restoration and protection projects), is currently stagnating the implementation of the coastal plan.

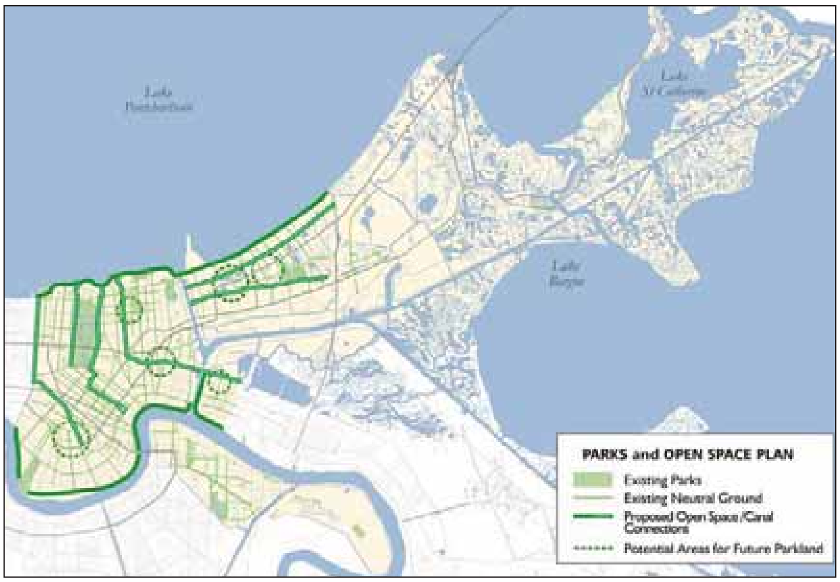
Even with adequate funding and access to land, the construction of more robust levees and wetlands will likely take at least a generation to implement. In the face of the dramatic wetland loss and relative sea level rise occurring in many parts of deltaic Louisiana, this may make only the thin ridges flanking the Mississippi River, various bayous in rural coastal Louisiana, and the dense impounded areas near and below sea level in the City of New Orleans salvageable for human habitation at the end of this century.

The current master planning process in New Orleans parish is dedicated to providing recommendations for sustainable built and natural habitats within the parish boundaries and surrounding parishes. The highest priority for infrastructure is a systemic infrastructure plan with improved agency coordination and investments that increase flood/hurricane resistance. However, a lesser level of support exists to date for investments in high-density areas and a low priority exists to invest in existing flood-resistant areas.

For example, from the public comments received to date in response to the series of community meetings convened as a part of the master planning process, a high priority was placed on adopting the "Dutch system" of water management (as in the "Room for the River" program adopted by the Netherlands government in 2006) to hold more water in the city with more canals and retention ponds and to repair/improve pumps and levees (Clancy 2008). However, low public support exists on instituting a comprehensive water management system or to use parks or vacant land for water storage, due to concerns about flooding, mosquito-borne disease, and a prevailing notion that the best way to manage water is to keep it outside of the city's boundaries. These seemingly contradictory impulses have not been resolved into a citywide recommended master plan or strategy.

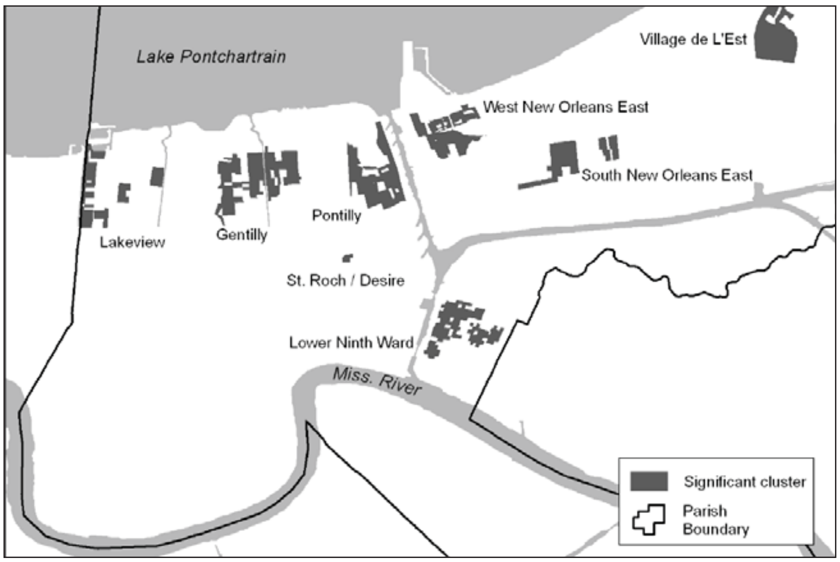
Further complicating the transition from residential use to a more natural ecostructure (e.g., water, green space, urban forest, etc) in areas of the city where a low percentage of residents are returning is a lack of public trust in government and developers. Maps produced in the immediate aftermath of Hurricane Katrina by the Urban Land Institute (ULI) and the Bring New Orleans Back Commission's (BNOBC) Urban Planning Committee depicted portions of low lying residential areas converted into wetlands or green space (Figure 3) at a time prior to the development of the Road Home Program, which provided for voluntary buyouts and restoration grants to homeowners. Thus, conversions to uses other than residential are generally not only seen as decreasing the market value of surrounding residential property, but also as potential plots to deny residents the right to return to their former homes.

FIGURE 3
Parks and Open Space Plan Outlining Potential Areas for Future Parkland as Presented to the General Public by the Bring New Orleans Back Commission Urban Planning Committee on January 11, 2006



In both the ULI and BNOBC cases, these maps and proposed land uses were met with public hostility. The City government did not endorse these recommendations and, instead, encouraged residents to repopulate the entire city. As of the summer of 2009, nearly four years after Hurricane Katrina, the City has numerous areas where less than 50% of residents have returned (GNOCDC 2009). Green and Olshansky evaluated the extent to which New Orleans homeowners exercised the "buyout" options in the Road Home program (i.e., selling their property to the Louisiana Land Trust and not returning to their pre-Katrina property). As depicted in Figure 4, numerous significant clusters of sellers have emerged from this voluntary program. Not surprisingly, all of these clusters are in lower lying areas of the city that were impacted the most from the flooding in the aftermath of Hurricane Katrina and are, in several cases, in the same regions of the city where the BNOBC Urban Planning Committee recommended land use changes to encourage open park land (Figure 3).

FIGURE 4
Significant Census Block Clusters with Many Sellers



The Lower 9th Ward offers a promising case study in New Orleans where community-based planning efforts have explored a number of rebuilding and land use strategies that embrace sustainability concepts. As early as June 2006, the Lower 9th Ward and Holy Cross Neighborhood produced a "sustainable restoration" plan which served as the foundation for its contribution to the Unified New Orleans Planning process (HCHDL9W 2006). Key concepts examined in the plan include structural improvements (e.g., energy efficiency and renewable energy) and open/degraded space ecostructural interventions (e.g., cypress swamp restoration, urban forestry) that promote safety, survivability and, ultimately, carbon neutrality. For example, the lower elevation impacted areas of the Lower 9th Ward, the community is supporting restoration of the adjacent Bayou Bienvenue to provide storm surge protection, wastewater assimilation from the neighborhood's water treatment plan, carbon sequestration, and recreational services. For residential areas with little reoccupation of homes and a high percentage of those participating in the State's buyout option, ideas ranging from urban farming, urban forestry, and community gardens and parks have been proposed.

If a new residential use does not materialize for these "buyout" properties throughout the city, a land use change and new "active" use would likely increase the market value for surrounding repopulated parcels in those neighborhoods and would be most fortuitous. But whether these clusters will see significant permanent land use changes incorporating water and/or park systems remains to be seen. However, with maintenance of community engagement, the passive stormwater runoff and retention as well as the aesthetic and recreational ecosystem services of these adaptation measures can lead to greater community support for investments in these interventions. To that end, the ability for the City and its residents to see water as not only a threat, but also an asset (i.e., living with water — not against it) will be a critical evolution from current prevailing norms.

5 LAND USE CHALLENGES AND OPPORTUNITIES

5.1 Natural Versus Engineered Systems

Engineered structures like levees and floodwalls are at odds with the natural delta-building processes that created Louisiana's coastal zone. However, given the human settlement patterns in Louisiana's deltaic plain, urban and regional levees and floodwalls continue to be planned in combination with targeted, more natural freshwater and sediment diversions in unpopulated areas to maintain as much ecostructure as possible. The construction cost estimates for proposed urban protection (New Orleans metropolitan area) and regional levee systems (Figure 10) have varied widely and steadily increased since original estimates developed by the U.S. Army Corps of Engineers shortly after Hurricane Katrina. These infrastructure cost uncertainties are the result of changes in construction costs each year due to the fluctuating price in oil, increased concern over stability of existing levee structures, increased costs associated with acquiring suitable building materials (e.g., clay for regional levees), increased costs of likely mitigation (e.g., land buyouts), and other design recommendations based on new predictive models to achieve the 100-year level protection that both these levees are designed to achieve (Table 2). While costs for the Orleans metropolitan levee system have generally ranged from \$3.5 billion - \$9.5 billion (protecting approximately 1 million current residents), costs for the proposed regional coastal levee (protecting approximately 120,000 current residents), originally estimated at \$4-5 billion, could double. This could further escalate up to ten-fold if costs for the Morganza-to-the-Gulf (MtG) Levee system increase from the original \$882 million estimate to \$10.77-11.2 billion, as tentatively proposed by Arcadis Corp — a contractor for the Army Corps of Engineers.

TABLE 2
Cost Projections for Repair of New Orleans Metro Area and Regional Coastal Levees and Corresponding Residential Populations

	New Orleans Metro Area	Southeast Louisiana	Reference(s)
Repair/ Construction Cost	$3.5-9.5 billion ($7.2 billion)	$4-5 billion [$882 M for Morganza to Gulf (MtG) 72-mile section] $10.7-11.2b for MtG (perhaps lower at $1.4-$1.5b if 30% increase)	(Walsh 2007; ENS 2006; Jonsson 2007) (Schleifstein 2008)
Area Protected	115,616 acres (Orleans Parish)	550,990 acres	(Jonsson 2007)
Residential Pop. Protected	1-1.3 million (320,000 in Orleans Parish est.)	120,000	(BIMPP/GNOCDC 2008)
Construction cost/resident (not including long-term maintenance)	$2,692-$9,500	$33,333-$41,667 $43,333-$54,167 $423,000-$528,750	Uses 2006/2007 estimate above. Assumes 30% cost overrun based on Governor's Office statement (Schlei-fstein 2008) Assumes 12.69 multiplier on earlier estimates based on new contingencies (Schleifstein 2008)

Concern regarding the uncertainties in levee costs are only exacerbated by additional uncertainties regarding their ability to physically protect their respective populations with a 1% probability of flooding in any given year as well as the uncertainties regarding what a 1 in 100-year flooding event really is, given the effects of climate change and other endemic environmental conditions described previously. For example, the recent 500-year flooding events in the Mississippi River Basin came just 15 years after a similar 500-year event in 1993 (Paulson 2008). As shown in Table 2, even if construction costs remain at their original estimates with the aim of protecting New Orleans metropolitan residents and Louisiana coastal rural residents, costs will be between:

1. $2,692-$9,500 per resident in the New Orleans metropolitan area; and
2. $33,333-$41,667 per resident in the rural areas.

The Louisiana Speaks Regional Plan for south Louisiana developed by Calthorpe Associates is a recent attempt by the State of Louisiana to apply smart growth and New Urbanist approaches to what is arguably the largest coastal master plan to be developed in modern history in the United States, covering more than 3 million acres of wetland and terrestrial rural and urban systems (LRA 2007). While this plan demonstrates success in incorporating restoration of coastal wetlands, construction of levees, reinvestment in historic communities, investments in new transportation and other infrastructure, and community-based development from tens of thousands of citizens and stakeholders, it implicitly contains a number of challenges:

1. It does not incorporate the latest knowledge of relative sea level rise impacts on Louisiana's deltaic region;
2. It assumes that the integrated coastal wetland restoration projects and large scale levee protection measures will be funded, implemented, and function collectively to maintain the current level of wetland habit, which is an issue hotly contested and uncertain at best; and
3. It promotes new growth around existing communities that would then warrant the investments in infrastructure described in the plan when, in fact, the population of rural coastal parishes like Plaquemines parish, for example, are continuing to decline, particularly since the hurricanes of the past three years (Adelson 2009).

5.2 Structural and Non-Structural Measures

How best to prioritize residential, commercial, recreational, and conservation land use in the Gulf Coast region remains an unresolved issue that has been extensively researched and discussed. The Interagency Performance Evaluation Task Force (IPET) was established in October 2005 by the U.S. Army Corps of Engineers to evaluate the performance of the New Orleans hurricane protection system during Hurricane Katrina and to provide assessments of remaining vulnerabilities of the urban and coastal systems (NAE/NRC 2008; NAE/NRC 2009).

The IPET conducted its evaluations in five areas:

1. Design and status of the hurricane protection system pre-Katrina;
2. Storm surges and waves generated by Hurricane Katrina;
3. Performance of the hurricane protection system during and after the storm;

4. Social-related consequences of Katrina-related damage; and
5. Risks to New Orleans and the region posed by future tropical storms.

Overarching IPET conclusions regarding structural and non-structural options include (54):

1. Comprehensive flood planning and risk management for the New Orleans metropolitan region will be based on a combination of structural and non-structural measures, the latter including relocation options, floodproofing and elevation of structures, and evacuation studies and plans;
2. Better risk communication also must be part of more effective mitigation and an improved state of preparedness; and
3. Structural measures, such as levees and floodwalls, should not be viewed as substitutes or replacements for nonstructural measures, but rather as complementary parts of a multi-tiered hurricane protection solution.

In terms of living with a prevalence of flooding, Kahan et al. (2006) looked at lessons for the Gulf that could be learned from the experiences of four catastrophic floods in the second half of the 20th century. They suggest that there has been an evolution in thinking about flood management that has taken place in the past 50 years from flood control to integrated water resource management (IWRM). IWRM is a shift from a near-exclusive focus on structural ways of controlling floods (such as building dams, levees and the like) to non-structural flood control systems such as laws and regulations, administrative management and economic levers, and technical measures other than construction (Kahan et al. 2006). The principles of IWRM are:

- efficiency to make water resources go as far as possible and achieve the desired level of protection at as little cost as possible;
- equity across different social and economic groups; and
- environmental sustainability, to protect the water resources base and associated eco-systems (Kahan et al. 2006).

The most recent IPET recommendations support a long-term plan for relocation in vulnerable areas, particularly, since the restoration and flood control measures will leave many residents in coastal parishes vulnerable to increased flooding for generations to come. More specifically, IPET supports that the planning and design for upgrading the current hurricane protection system should discourage settlement in areas that are most vulnerable to flooding due to hurricane storm surge. The voluntary relocation of people and neighborhoods of particularly vulnerable areas — with adequate resources designed to improve their safety in less vulnerable areas-should be considered as a viable public policy option (NAE/NRC 2009). When the primary presenting issue is flood protection, non-structural measures are manifested in such examples as zoning to prohibit development of floodplains, flood insurance requirements and limitations, storm surge barriers instead of levees in some places, "land swapping" to relocate residents into lower-risk (e.g., higher or better protected) areas, and even returning some of the land to the water (Kahan et al. 2006).

One of the challenges of non-structural approaches to flood control in the Gulf region is that there are many different actors, including the federal and state governments, local governments, engineers, the private business sector, and communities, all having differences in preference for different measures. The benefits and costs of various strategies are poorly understood, particularly given uncertainties in regional economic growth.

Another major issue is the heavy reliance on structural approaches to reduce flood risk versus non-structural (e.g., zoning, planning, easements, etc) measures. With regard to structural approaches, the science and engineering uncertainties regarding environmental trends (e.g., rate of sea level rise and subsidence) and performance of restoration and protection structures (e.g. levees built on unstable soils) make the success of these approaches highly speculative. In addition, uncertainty about the future level and distribution of protection and restoration will continue to affect investments in the built and natural environment and the individual and collective decisions that ultimately shape the scope of reconstruction. Non-structural measures to consider are also not well defined and there is a general lack of awareness of available options, and what the experiences have been when various measures have been attempted in similar and dissimilar situations worldwide. Furthermore, the high reliance on voluntary participation structure-raising of homes and property buyouts of vulnerable residents in coastal Louisiana as proposed in the CPRA master plan is of concern (CPRA 2007).

5.3 United Houma Nation Case Study of Adaptation and Mitigation

One promising case study of community-based adaptation and mitigation to climate change in Louisiana is that of the United Houma Nation (UHN). The UHN constituents lie primarily outside levee protection systems described above and within the coastal area depicted in Figure 1 at the southern extreme of the LaFourche-Terrebonne delta. For centuries, UHN settlements were physically and culturally integrated with a vibrant healthy ecosystem that sustained and protected their settlements. This deep connection with natural ecostructure is eloquently expressed by historian Daniel D'Oney who wrote "Understanding the Houma without acknowledging their relationship to waterways is like trying to understand a shadow without acknowledging the existence of light".

The tension between coastal communities' cultural connection to a delta system and its rapid erosion is a common phenomenon in vulnerable deltas in both the developed and developing world. Thus, the experiences of the UHN, because they live on the most rapidly eroding delta in the world, provide lessons for other deltaic communities. For generations, European colonization, warfare, disease, land dispossession, and coastal erosion have threatened the UHN. During the 20th century, the 16,000 members of the UHN were faced with declining livelihoods and displacement due to accelerated coastal erosion, saltwater intrusion, and the decline of the Barataria-Terrebonne Estuary. Estimates suggest that Hurricanes Katrina and Rita in 2005 directly affected over 7,000 tribal members with nearly half of these displaced. Hurricane Katrina left over 1,000 tribal members homeless in small settlements through lower Plaquemines, St. Bernard, and Jefferson Parishes and the storm surge from Hurricane Rita inundated lower Lafourche and Terrebonne parishes devastating 4,000 homes of tribal members (Yoachim 2008).

Following the storms, the UHN mobilized to provide immediate relief and support in the form of shelter, food, and necessities to members. With recovery efforts continuing, there is recognition within UHN tribal communities that, to survive, members must have their homes elevated or relocate inland to higher ground. Perhaps the greatest concern of the Houma people is community cohesion. While the needs of individual Houma citizens are addressed, the tribe is very concerned that the historic Indian communities are themselves at risk. Indigenous existence is based on a connection between people and place (in this case, a physical and cultural connection to water natural resources) and this is the foundation of all that is indigenous culture. So, for the UHN, the immediate needs must be balanced against the long-term sustainability and survivability of the community. In the near-term, the UHN has begun to develop an emergency response plan with the intent to be certified as a Community Emergency Response Team by the Department of Homeland Security with a core of trained members of the Houma nation available to serve as first responders in their communities.

In terms of long-term adaptation to climate change, the UHN is embarking on a relocation strategy that is among the first for coastal communities in the United States to date. The hope for the UHN will be to identify new lands that maintain their connection to water while reducing their vulnerability to periodic and disaster-related flooding through non-structural and structural measures. While the mechanism for land acquisition and assemblage is still being researched, land policy options, including land trusts, are emerging as the most critical tools (Meffert, Etheridge and Tate 2009).

5.4 Easements, Mitigation Land Trusts, and Severance of Surface/Mineral Rights

Even with the best science and engineering informing the optimal balance of ecostructure and hard structures for Louisiana's urban and coastal planning, the implementation of land use interventions (and legal consequences) remains the biggest challenge the State of Louisiana faces on adaptation and mitigation measures. Jurisdictional challenges are exacerbated by the high proportion of private property ownership in Louisiana's coastal zone (80%) and laws that tend to favor private property owners. The amount of science and engineering-related research conducted in the Louisiana coastal zone is vast relative to that often conducted in developing countries. While uncertainty and debate will continue over the ability of large-scale habitat restoration and levee construction to protect urban and rural settlements from the effects of climate change, there is general agreement on the basic natural ecological functions that are key to reducing population vulnerability and maintaining healthy, viable communities.

The carbon sequestration benefits of Louisiana's coastal wetland and forested habitats is emerging as an increasingly significant driver in exploring various land use policies that promote restoration and conservation of these private and public lands. For example, an acre of restored bottomland hardwood in the lower Mississippi floodplain sequesters up to 300 tons (average of 100 tons) of carbon dioxide over the next 100 years (Wayburn 2009). In addition, the highly productive fresh to brackish marshes of Louisiana's coastal zone contain some of the highest amounts of soil organic carbon in the United States, and thus also represents great potential for carbon sequestration (Markewich and Russell 2001).

Even with the legal challenges described above, there are several land policy opportunities in coastal Louisiana that can provide for large-scale adaptation and mitigation while preserving the rights of Louisiana's citizenry. As described above, land policy opportunities extend to the coordination and expediting of restoration and protective measures for critical landforms, including bays, shorelines, and peninsulas of urbanized and rural areas of coastal Louisiana. Sustainable development practices include compact development, preservation of open space and natural resources, neighborhood scale storm water management, water efficiency, brownfield redevelopment, and overall smart growth principles. Recommendations including these were included in the reports submitted to the City of New Orleans and the general public prior to 2007 (Urban Design Committee 2006). While these recommendations were not initially put into practice by New Orleans' municipal government due to sociopolitical and jurisdictional concerns, among other reasons, the New Orleans Office of Recovery and Development Administration and Coastal Protection and Restoration

Authority have subsequently endorsed many of them (CPRA 2007; CPRA 2009; NOLA 2009).

Although not yet implemented in Louisiana, "rolling easements" are one viable near-term adaptive land policy in coastal Louisiana. Rolling easements are easements placed along shorelines that prevent property owners from "holding back the sea" but still allow them to develop their land (Emmer et al. 2007). In other words, these easements do not restrict further development or redevelopment of private property until it erodes, such that the government would compensate them for their eroded land if it were to be used for the public good (e.g., for coastal restoration). Although rolling easements do not aggressively address long-term mitigation strategies, they can be a useful near-term strategy that obtains early buy-in from the private land owners for a future public land use with minimal near-term costs and no initial limitations on development of non-eroded land.

One of the more creative financial mechanisms to reduce risk and maximize conservation and restoration is the State Conservation and Mitigation Trust Fund, recommended by the Louisiana Speaks Initiative and supported by the Louisiana Recovery Authority (LRA 2007). This fund would allow the State to acquire fee ownership or surface rights to high-risk lands or acquire permanent conservation easements. Given the prevalence of private property ownership in coastal Louisiana, this would allow potential sellers the option for retention of underlying mineral rights (through legal severance of surface and underlying rights) and, thus, enhance the potential for voluntary relocation to less vulnerable areas. There are successful precedents for this approach with Louisiana's coastal restoration efforts. For example, on property with State-owned surface rights, the State can allow a landowner access for private oil & gas exploration purposes with the caveat that it be maintained and closed in a manner that does not disturb natural and built elements of the conservation or restoration intent.

Although severance of surface and mineral rights provides for a useful alternative to complete property transfer, these mineral rights certainly complicate the acquisition of land rights in south Louisiana. Given Louisiana's relative abundance of natural gas and oil reserves in its coastal region, the subsurface mineral rights are often more valuable than most other practical surface land use rights, particularly when these properties are not at or adjacent to population centers and/or land ridges or levees. Therefore, the extent to which mineral rights can be retained by a property owner while surface rights are utilized for coastal habitat conservation or restoration enhances the ability to implement these projects. While Louisiana law does not generally allow for permanent severance of surface rights from mineral rights, exceptions have been granted in the cases where that severance would promote coastal restoration, protection, or conservation efforts.

Given the high private property ownership rate in coastal Louisiana and that large scale restoration efforts involve a multitude of properties and landowners, even if the majority of land rights are to be acquired through direct purchase, lease, or donation, it is highly likely that, for any given project, some entities will refuse to enter into those agreements. For these properties, there will be no other option than eminent domain proceedings. Until recent legislation, Louisiana was the only one of the 50 United States that allowed compensation for "full extent of loss" in the case of eminent domain, which effectively fatally crippled most projects that involved any uncooperative landowner. However, with Constitutional Amendment #4-Act 853 of the 2006 Regular Session (SB 27 by Senator Reggie Dupre), compensation for this expropriation for flood control or coastal restoration is now defined at the fair market value, which is a step towards large-scale restoration at non-prohibitive cost and time-consuming implementation.

6 APPLICATIONS OF THE NEW ORLEANS CASE STUDY TO THE DEVELOPING WORLD

The rapidly growing urbanized regions in low-lying coastal settings worldwide face numerous habitat, infrastructure, and non-structural challenges due to expected sea-level rise in the next century and beyond. However, the severity and timing of adverse impacts will vary, depending on endemic conditions including topography; local relative sea-level issues (e.g., with subsidence adding to vulnerability); and the probability of natural disasters, including major storms, tsunamis, and other phenomena.

Within this context, New Orleans is often described as "a canary in the global warming coal mine" (Törnqvist and Meffert 2008). Regardless of how this particular city will be rebuilt, New Orleans and its deltaic surroundings offer an opportunity to adapt both a coastal urban center and its inextricably-linked surrounding natural ecosystem such that natural ecosystem functions and economic goods and services can work together to the best extent possible. More specifically, New Orleans physical viability into the 21st century depends, to a large extent, on the ecological health of its surrounding coastal wetlands in terms of the resultant economic and storm surge protection values of these habitats. Conversely, the justification for large-scale restoration of these habitats lies with the goods and services these wetlands provide the world and the protection they give to densely populated areas and strategic port systems. New Orleans, in this sense, is an urban and natural laboratory that can provide new knowledge and understanding with applicability to larger cities like Shanghai, Tokyo, and New York City and similar regional deltaic forms in the developing world including, but not limited to, the Mekong Delta in Viet Nam and the Ganges/Brahmaputra/Meghna (GBM) river and deltaic systems.

In this paper, we argue that the New Orleans, Louisiana case study can be used as a model system in a developed country that can help inform policies and practices in the developing world, utilizing natural processes and resources whenever possible for climate change adaptation. As evidenced by discussions earlier in this paper of the vast amounts of research and planning that have focused on gradual environmental degradation and post-disaster recovery of New Orleans and the Gulf of Mexico coast, coastal Louisiana is a "data-rich" urban and ecological case study that can help inform scientific understanding and land use planning in more "data-poor" developing countries that are experiencing similar global threats. Global climate change does not discriminate between the post-industrialized and developing nations in the world, other than in the level of vulnerability they exhibit and differences in investment capacity and priorities (Halsnaes and Verhagen 2007).

Of particular relevance are delta regions and their urban center, increasingly vulnerable to SLR and storm surges like Dhaka, Bangladesh, and its GBM river system (Figure 5). Cities like Dhaka can benefit from lessons learned in coastal Louisiana not only in terms of climate change adaptation (and related restoration of delta systems for storm surge protection) but also, indirectly, in terms of urban poverty alleviation. This latter benefit, although perhaps not immediately intuitive, is due to the fact that the vast majority of new immigrants to Dhaka come from Bangladesh's rural areas, with many of these immigrants migrating north from the delta regions because of their rapid erosion. While the body of peer-reviewed literature related to climate change impacts on the GBM system is expanding in recent years (Ali 1999; Brouwer et al. 2007; Erwin 2009; Karim and Mimura 2008; McDougall 2007; Mirza, Warrick and Ericksen 2003), a thorough comparative analysis of Louisiana and Bangladesh trends and options for future adaptation has not yet been published.

Coastal Louisiana and Bangladesh are on the same order of magnitude but with Bangladesh exceeding Louisiana in almost every metric of resource abundance and vulnerability. Flows of the Mississippi River are 600,000 cubic feet per second (cfs) on average and are about one-third of the GBM combined flow (1,511,750 cfs average). Whereas Louisiana's coastline is 639 km along the northern Gulf of Mexico, Bangladesh's coastline is 710 km along the Bay of Bengal. (Karim and Mimura 2008) The coastal zone of Bangladesh comprises 19 administrative districts encompassing a land area of 47,201 km2 (Figure 6) compared to Louisiana's 19 coastal parishes with 21,448 km2 of designated coastal zone area. A three-foot rise in sea levels could inundate nearly 20% of Bangladesh's territory — proportionately on the same scale as Louisiana. As mentioned earlier, the 9mm per year of relative sea level rise in Louisiana is greater than the 4-7 mm per year being experienced in Bangladesh's coastal zone. (Karim and Mimura 2008).

In terms of human vulnerability, Bangladesh and Louisiana vary depending on whether one is assessing coast-wide or urban exposure. In terms of overall human vulnerability, Bangladesh exceeds Louisiana with 14M people residing in its coastal zone (541 residents per km2) compared to Louisiana's 2M coastal zone residents (93.3 residents per km2). However, in terms of urban centers, while both Dhaka and New Orleans are relatively flat, Dhaka's average elevation is 4m (between 1 and 14m) while the vast majority of New Orleans is less than 4m in elevation (Lewis 2009), with 50% of Orleans parish being below sea level, making New Orleans' urban infrastructure even more vulnerable to the near term effects of climate change, in particular relative sea level rise (Campanella 2007).

Similar comparative practices can be examined in terms of predicting vulnerability to increasingly intense tropical storms and providing maintenance and restoration of these natural coastal habitats that furnish storm surge protection and other ecosystem services. US and Japanese models, for example, have been used to enhance storm surge predictive capacity of Bangladesh in recent years (Karim and Mimura 2008; AMS 2008). Recently, when cyclone SIDR was forming in the Bay of Bengal on November 12th, 2007, a storm surge modeler, Dr. Hassan Mashriqui, at Louisiana State University used his Gulf Coast "data-rich" model for Louisiana to predict a 12 foot storm surge for Bangladesh that would go 20-50 miles inland (Society AM 2008). After communicating this prediction to Bangladesh's disaster office (their equivalent of FEMA), they were able to evacuate 3.2 million residents. Although 3,500 casualties still occurred, countless lives were saved.

Bangladesh has the Coastal Greenbelt Project to slow down surge waves and stabilize coastal land (afforestation project) (Erwin 2009). However, Bangladesh's development priorities also include more immediate concerns regarding poverty alleviation: expanding energy access to the poor, increased food production as well as adaptive measures against flooding, coastal erosion, saltwater intrusion, and droughts (Halsnaes and Verhagen 2007). Thus, as modeled by Hallegatte and Hourcade, developing countries that have a high prevalence of natural disasters (e.g., increased flooding and/or intensity of storms) also have significant impediments to long-term economic development. This is because significant GDP losses result from short-term climate change impacts and preclude investments in long-term economic adaptation measures (Hallegatte and Hourcade 2005).

FIGURE 5
The Coastal Regions of Bangladesh and Major Rivers in the Western Coastal Zone (reprinted from Karim and Mimura 2008 with permission from Elsevier)

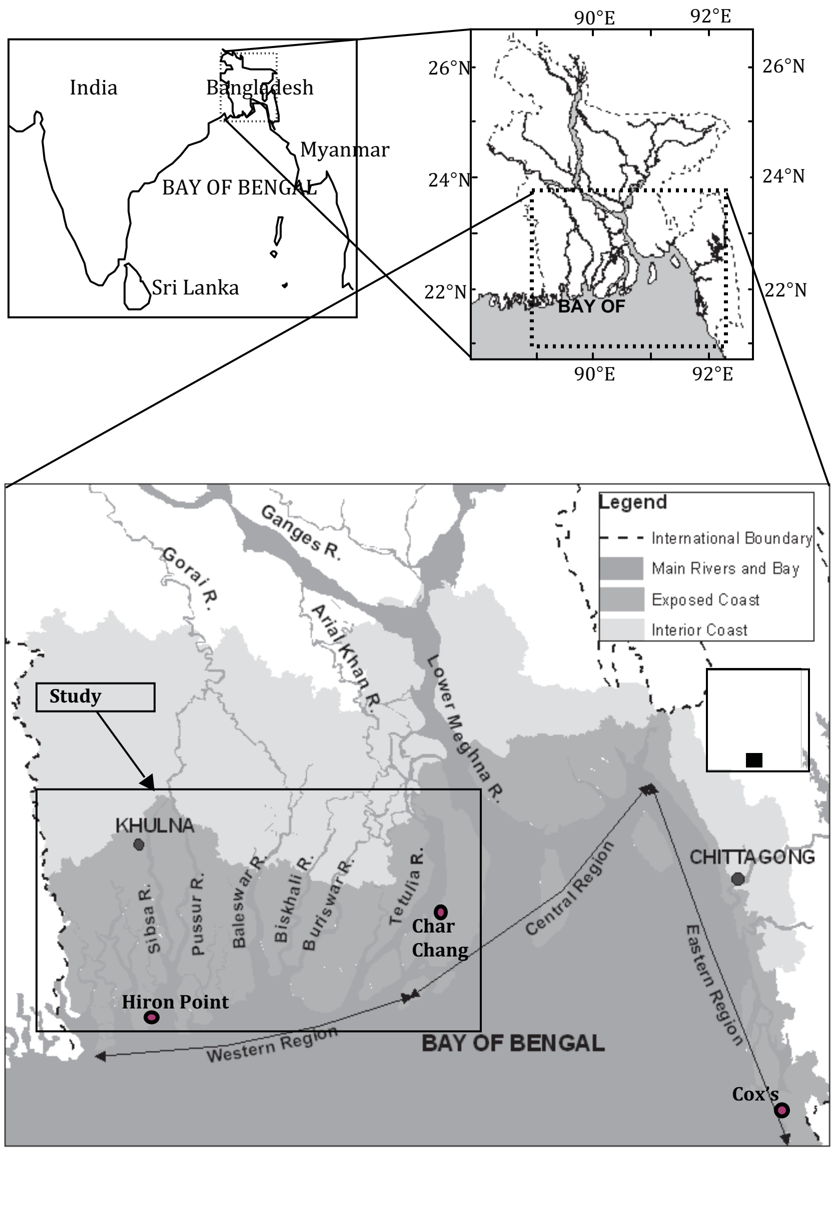
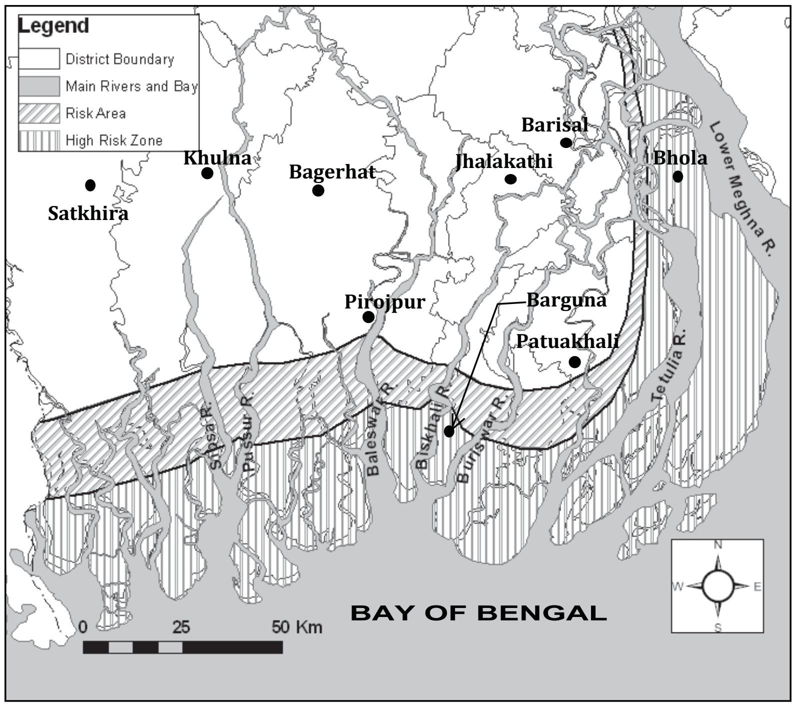


FIGURE 6
Flood Risk Map and Planning Districts for Coastal Bangladesh



Reprinted from Karim and Mimura 2008 (69) with permission from Elsevier.

In this sense, although the general quality of life is higher than developing countries, coastal Louisiana is similarly challenged in terms of investments in long-term adaptation. With four major storm surge-related flooding events in the past three years resulting in hundreds of billions in total damage to the Gulf coast, and more than $150 billion from Hurricane Katrina alone (Hallegatte 2008), Louisiana may not be able to raise necessary funds to maintain its current level of natural functioning. For example, although the State of Louisiana has increased its restoration and flood control needs with investments at $1.4 billion over the next four years from a combination of state and federal sources (Kirkham 2009), the current master plan will cost up to $100b (CPRA 2009). Even with these financial limitations, there are lessons learned in terms of Louisiana's Mississippi River freshwater and sediment diversion projects that can be applied to increasingly flood prone delta systems. Case studies have emerged in Beel Bhaina, for example, where water and sediment from the Ganges is now diverted into shallow lands prone to flooding and saltwater intrusion to promote natural wetland accretion and offsets to erosion exacerbated by sea level rise (Sengupta 2009). In some places in coastal Bangladesh, sediment-laden river water sped up by a series of man-made dams and channels has actually gained land over the last 35 years, much like the sediment rich waters whose delta-building capacity has been enhanced in Louisiana's Atchafalaya River and Wax Lake deltas (CPRA 2007; LCWCRTF 1993).

7 CONCLUSIONS

Through qualitative analysis and synthesis of available literature, this paper used the City of New Orleans and its surrounding Louisiana coastal wetlands as a case study to examine the following hypothesis: restoring and enhancing ecosystem services (i.e., "ecostructure") of urban systems in the context of regional natural systems increases the ability of these urban systems to adapt to and mitigate the effects of climate change. In addition, climate change adaptation and mitigation of these complex systems required both regional appropriate jurisdictional oversight and local governance.

What are the main ecological drivers of change on regional and local scales that impact urban resilience following a disaster and adaptation to climate change? The fate of New Orleans and other delta cities worldwide is one of increasing vulnerability during the next century and beyond. However, these communities have always been proximate to the natural periodic and catastrophic threats that face them and can survive as long as they are adaptable and live with these prevailing gradual environmental trends (e.g., coastal erosion, sea level, rise, and subsidence) and systemic "shocks" (e.g., hurricane storm surge damages). New Orleans and coastal Louisiana are worth restoring and conserving because of the vast tangible and intangible economic, ecological, and cultural values intrinsic to their ecosystems and human communities. These include a significant vibrant and culturally rich population in New Orleans as well fisheries, oil, gas and other infrastructure elements in coastal Louisiana.

What is the role of ecosystem services and land use transformation in promoting human well-being and safety, reducing vulnerability, and enhancing adaptation and mitigation to climate change? Based on our findings, Louisiana's coastal wetlands have limited ability to maintain elevation relative to rising sea level and to sustain the ecosystem services described above. Thus, the future design of the natural and built environment must also accommodate periodic flooding and increased vulnerability to storm surge (Day and Giosan 2008). Regional plans need to incorporate both adaptation and mitigation to address the chronic vulnerabilities of this integrated urban and natural system; opportunities exist for creative structural and non-structural interventions and policies described above.

What are the spatial, jurisdictional, and temporal scales required to ensure sustainable governance of urban systems? The Louisiana coastal master plan is an ecologically-based strategy that seeks to protect local urban developments like New Orleans and sustain critical regional fisheries and port economies in the face of anticipated relative sea level rise and potential increased storm intensities associated with climate change. This strategy is multi-decadal with large-scale restoration project timelines being 20 years or greater. The spatial scale of the State's master plan is the entire coastal zone including the deltaic plain of the Mississippi River and the adjacent western coastal habitats, thus involving numerous parishes, cities, and towns that must coordinate their governance boundaries with corresponding hydrologic basin management strategies for success.

The prevailing practices in place on the urban, regional, and statewide scales have largely relied on adaptive measures. Many opportunities for mitigation remain including 1) increased GHG sequestration through ecosystem services provided by the restoration of natural delta processes and wetland creation, 2) GHG regulation of oil and gas industries in the State, and 3) GHG reductions through increased use of renewable energy sources. However, most of these measures remain early in development and are largely voluntary and market-driven on local, state and federal levels. Coastal restoration projects implemented to date are largely smaller in spatial and temporal scale and limited in terms of restoring large-scale natural processes.

There is reason for optimism that there will be an increased emphasis on climate mitigation and adaptation at both the city and coast-wide scales. On the local urban scale, New Orleans' Comprehensive Master Plan advocates implementation of mitigation measures described above within its jurisdictional boundaries and advocating for them on a regional scale. The State of Louisiana is also advocating large-scale coastal restoration and other structural and non-structural adaptation measures.

The challenge remaining ahead rests primarily on two issues – limited funding and land use policy implementation on the local urban and regional coastal scales. While the State has a long record of rapid implementation of takings of land for the purpose of adaptive measures like levees and pumps, its record on takings or other creative land use options that maintain private landownership for large scale coastal restoration adaptive measures is limited. From this perspective, the science and engineering behind citywide and coast-wide adaptation is well-studied, whereas the legal and financial hurdles require much more investments in decision-making and policy.

The $4 billion initial investment in CPRA-recommended regional levee systems (including the 72-mile Morganza-to-Gulf levee) is an expensive adaptation investment that, while potentially providing near-term protection from flooding for the Houma urbanized area and its residents, could ultimately lose time, money, ecosystem services, property and life, if large-scale coastal wetland restoration projects are not also prioritized. In other words, these regional levee systems will not be stable if their surrounding natural wetlands are not stable. Because of the existing and future likely prospects of funding for large-scale levees, coastal restoration, and other flood protection, more institutionalized investments in non-structural measures to protect Louisiana's coastal communities is critical. Specific potential actions that should be examined carefully include:

1. Relocation of thousands of rural inhabitants in the next 10-20 years - particularly those in vulnerable coastal areas outside of the proposed levee protection system (e.g., UHN members described previously).

2. Relocation of up to 120,000 rural (e.g., Buras) and potentially urban (e.g., Houma) inhabitants in areas marginally protected by regional levee systems and increasingly at risk due to sea level rise and disasters in the next 50-75 years.

3. Re-examination of "permanent" versus "temporary" structures for lodging or other longer-term residences in these vulnerable areas so that regional economies can be maintained.

4. Implementation of a State Conservation and Mitigation Trust Fund to promote conservation easements and/or land buyouts and including the option of separation of land, mineral or other rights associated with currently owned private property.

To accomplish this, scientists and engineers must work closely with designers, economists, planning practitioners, community representatives, and political leadership at the conception of demonstration projects and policy development. Lawmakers, planners and architects must not only seek out the best and worst case studies to inform their practice but embrace the scientific and engineering underpinnings for the most sound application and maintenance of ecosystem services. Urban systems like New Orleans can ultimately be more resilient to gradual and catastrophic events, and therefore more sustainable, when their contextual natural and social environments are resilient as well.

Delta habitats are among the most fertile lands in the world and can continue to provide fisheries, agricultural products, and other ecosystem services to their coastal rural and urban communities and the rest of the world. In the case of the many urbanized and engineered delta systems worldwide, maximizing the natural processes that created these dynamic systems in the first place may also prove the cheapest and most practical way to protect their human populations from the effects of climate change into the next century. These inextricable links between the natural and built environments are at the core of ecostructure solutions in the New Orleans case study and, with appropriate attention to institutional differences, have application to similar deltaic regions worldwide.

While the original “ecostructure” hypothesis in this paper remains neither proven nor disproven, it is a question for which an answer will play out in the decades to come as the large-scale efforts to restore natural delta building are implemented and thereafter have a chance to perform successfully. The 2010 Deepwater Horizon oil spill in the Gulf of Mexico, despite its near-term and potential long-term threat to this fragile ecosystem, further supports the value of natural processes in sustaining deltaic habitats. The Mississippi/Atchafalaya rivers and related freshwater diversion projects have been successful tools for keeping the oil out of these habitats in the first place. This event has also catalyzed the development of a recovery plan that increases support for rapid implementation of these restoration projects, and supports accelerated investments in renewable energy options for the region, thus also helping to mitigate climate change.

References

Adelson, J. (January 2, 2009). “Recovery Jobs Spur Metro Migration.” Times-Picayune, Section Metro: 2.

Ali, A. 1999. “Climate Change Impacts and Adaptation Assessment in Bangladesh.” *Climate Research* 12: 8.

AMS. 2008. “LSU Warns Bangladesh Ahead of Monstor Cyclone’s Storm Surge.” *American Meteorological Society* (February 2008): 1.

BIMPP/GNOCDC. 2008. “The Greater New Orleans Index: Tracking Recovery of New Orleans and the Metro Area.” ed. Center BIMPPGNOCD, 53. New Orleans, LA.

Blakely, E.J. 2007. “Urban Planning for Climate Change.” Lincoln Institute of Land Policy Working Paper, Product Code: WP07EB1: 25.

Boesch, D.F. 1982. “Modifications in Louisiana, Causes, Consequences and Options.” Proceedings of a Conference on “Coastal Erosion and Wetlands,” Washington, DC: U.S. Fish and Wildlife Service BSP.

Brouwer, R., Akter S., Brander L., and Haque E. 2007. Socioeconomic Vulnerability and Adaptation to Environmental Risk: A Case Study of Climate Change and Flooding in Bangladesh.” *Society for Risk Analysis* 27 (2): 14.

Campanella, R. 2007. “Above Sea-Level New Orleans: The Residential Capacity of Orleans Parish’s Higher Ground.” Ed. Meffert D.J., 8.

Campanella, R., Etheridge D., and Meffert D.J. 2004. “Sustainability, Survivability, and the Paradox of New Orleans.” In *Urban Biosphere and Society: Partnership of Cities*, ed. Alfsen-Norodom C., B. Lane, Vol. 1023. New York: Annals of the New York Academy of Sciences.

Clancy, G. 2008. “Citywide Forum 3 Small Group Summary Findings.” ed. Orleans CoN (New Orleans Master Plan and Comprehensive Zoning Ordinance, New Orleans): 6.

Coreil, P.D. 1994. *Wetlands Functions and Values in Louisiana*. Baton Rouge, LA: Louisiana State University CES.

Costanza, R. & Farber S.C. 1985. *The Economic Value of Wetlands in Louisiana: Final Report*. Baton Rouge, LA: Louisiana Department of Natural Resources CMD.

Costanza, R., Mitsch W.J., and Day J.W. 2006. “Creating a Sustainable and Desirable New Orleans. *Ecological Engineering* 26 (4): 317–20.

CPRA. 2007. *Integrated Ecosystem Restoration and Hurricane Protection: Louisiana's Comprehensive Master Plan for a Sustainable Coast.* Baton Rouge, LA.

CPRA. 2009. *Draft Fiscal Year 2010 Annual Plan: Ecosystem Restoration and Hurricane Protection in Louisiana.* Baton Rouge, LA.

Day, J.W., and Giosan L. 2008. "Survive or Subside?" *Nature Geoscience* 1 (March 2008): 2.

Day, J.W., and Templet P.H. 1989. "Consequences of Sea Level Rise: Implications from the Mississippi Delta." *Coastal Management* 17: 7.

Duffy, W.G., and Clark D. 1989. "Marsh Management in Coastal Louisiana: Effects and Issues." Proceedings of a Symposium, Baton Rouge, LA: U.S. Fish and Wildlife Service RaDaLDoNR, Coastal Management Division, Biological Report.

Dyer, C.L., and Leard R.L. 1994. Folk Management in the Oyster Fishery of the U.S. Gulf of Mexico. *Fok Management in the World's Fisheries*, ed McGoodwin CLDaJR, 55–89 Niwot, CO: University Press of Colorado.

Emmer, R.E., Wilkins J.G., Schiavinato L.C., Davis M., and Wascom M. 2007. *Hazard Mitigation and Land Use Planning in Coastal Louisiana: Recommendations for the Future,* ed. Program LSGC (Louisiana State University, Baton Rouge, LA): 68.

ENS. March 31, 2006. "New Orleans Levee Repair Price Triples." Environmental News Service Newswire: 5.

Erwin, K.L. 2009. "Wetlands and Global Climate Change: The Role of Wetland Restoration in a Changing World." *Wetlands Ecology Management* 17: 14.

GCA. 2008. "Sustainable Systems Working Group Draft Goals and Policies." In *New Orleans Master Plan and Comprehensive Zoning Ordinance* (Goody Clancy Architects, New Orleans): 9.

GNOCDC. July 26, 2009. "Data File: Of the 73 N.O. neighborhoods, which one has shown the lowest recovery of occupied homes?" Times-Picayune, Section Metro: 1.

Good, B., et al. 1995. *Louisiana's Major Coastal Navigation Channels.* Baton Rouge, LA: Louisiana Department of Natural Resources CRD.

Hallegatte, S. 2008. "An Adaptive Regional Input-Output Model and its Application to the Assessment of the Economic Cost of Katrina." *Risk Analysis* 28 (3): 21.

Hallegatte, S., and Hourcade J. 2005. "Why Economic Growth Dynamics matter in Assessing Climate Change Damages: Illustration On Exreme Events." *Elsevier Science* 25.

Halsnaes, K., and Verhagen J. 2007. "Development based Climate Change Adaptation and Mitigation — Conceptual Issues and Lessons Learned in Studies in Developing Countries." *Mitigation Adaptation Strat Glob Change* 12: 20.

HCHDL9W. 2006. Sustainable Restoration: *Holy Cross Historic District & Lower 9th Ward*, ed. BNIM Architects BBL, and Bill Becker New Orleans, 48.

IPCC (2007) Climate Change 2007: Synthesis Report, Annex II Glossary. eds Baede APM, van der Linden P, & Verbruggen A), p 30.

Jonsson, P. 2007.() "Can a 'Leaky Levee' Save the Louisiana Coast?" The Christian Science Monitor, 2, January 24, 2007.

Kahan, J.P., M. Wu, S. Hajiamiri, and D. Knopman. 2006. "From Flood Control to Integrated Water Resource Management: Lessons for the Gulf Coast from flooding in other places in the last sixty years." In *RAND Corporation Occasional Paper*, ed. Institute RGSP (Rand, Santa Monica, CA), 46.

Karim, M.F., and Mimura, N. 2008. "Impacts of Climate Change and Sea-level rise on Cyclonic Storm Surge Floods in Bangladesh." *Global Environmental Change* 18: 11.

Kesel, R.H. 1989. "The Role of the Mississipi River in Wetland Loss in Southeastern Louisiana, U.S.A." *Environmental and Geological Science* 13: 11.

Kirkham, C.) "Money to Restore Coast is Cresting." The Times-Picayune, Section Front Page, 2, April 19, 2009.

LCWCRTF. 1993. *Coastal Wetlands Planing, Protection and Restoration Act, Louisiana Coastal Wetlands Restoration Plan: Main Report, Environmental Impact Statement and Appendices.* Baton Rouge, LA: U.S. Environmental Protection Agency USACoE, U.S. Fish and Wildlife Service, National Marine Fisheries Service, Natural Resources Conservation Service, and Louisiana Department of Natural Resources.

Lewis, D. 2009. *Strategic Retreat: An Adaptation Plan for Developed Coasts Susceptible to Sea Level Rise,* ed. Design HGSo (Harvard Graduate School of Design), 27. Cambridge, MA.

Lopez , J. 2007. "Status of Coastal Planning in Louisiana." In *NOGS Log* (New Orleans Geological Society, 7. New Orleans, LA, United States.

Lopez, J.A. 2005. *The Multiple Lines of Defense Strategy to Sustain Louisiana's Coast.* New Orleans, LA: Foundation LPB.

LRA. 2007. *Louisiana Speaks Regional Plan: Vision and Strategies for Recovery and Growth in South Louisiana. Main Report and Appendices*. Baton Rouge, LA.

Markewich, H.W., and Russell G.R. 2001. *A guide to potential soil carbon sequestration: Land-use management for mitigation of greenhouse gas emissions.* U.S. Department of the Interior USGS.

Marshall, B. "Losing Louisiana." Times-Picayune, 5, December 14, 2008.

McDougall, D. 2007. "Stemming the Tide." In *Ecologist*: 5.

McGuire, T. 2006. "Louisiana's Oysters, America's Wetlands, and the Storms of 2005." *Amercan Anthropologist* 108 (4): 692–705.

Meffert, D.J. 2008. "The Resilience of New Orleans: Urban and Coastal Adaptation to Disasters and Climate Change." In *Lincoln Institute of Land Policy Working Paper, 12.* Lincoln Institute of Land Policy, Cambridge, MA.

Meffert, D.J., Etheridge, D., and Tate J. 2009. *United Houma Nation: Draft Strategic Plan Technical Document, 20,* ed. Meffert + Etheridge L New Orleans, LA).

Meffert, D.J., et al. 1997. *The 1997 Evaluation Report to the U.S. Congress on the Effectiveness of Louisiana Coastal Wetland Restoration Projects in accordance with the Coastal Wetlands Planning, Protection and Restoration Act, Public Law 101-646, Title III or "Breaux Act".* Louisiana Department of Natural Resources, Baton Rouge, LA, Force LCWCaRT.

Mendelssohn, I.A., Turner R., and McKee, K.L. 1983. "Louisiana's Eroding Coastal Zone; Management Alternatives." *Journal of Limnology and Society South Africa* 9: 13.

Mirza, M.M.Q., Warrick R.A., and Ericksen N.J. 2003. "The Implications of Climate Change on Floods of the Ganges, Brahmaputra and Meghna Rivers in Bangladesh." *Climatic Change* 57: 32.

NAE/NRC. 2009. *The New Orleans Hurricane Protection System: Assessing Pre-Katrina Vulnerability and Improving Mitigation Preparedness,* ed. Projects CoNORHP (National Academy of Engineering and National Research Council), 41. Washington, DC.

NAE/NRC. 2008. *Fourth report of the National Academy of Engeineering/National Research Council Committee on New Orleans regional hurricane protection projects: review of the IPET Volume III,* ed. Projects CoNORHP (National Academy of Engineering and National Research Council), 19. Washington, DC.

NCMGCEC. 2006. *Taking a Longer View: Mapping for Sustainable Resilience*, ed. Constraints NCtMGCE (Regional Plan Association, the University of Texas at Austin, and EDAW), 12.

NOLA. 2009. *Draft Executive Summary: New Orleans master plan and comprehensive zoning ordinance*. New Orleans: Administration CPCaOoRaD.

Paulson, A. "Floods Engulf Archaic Levee System." The Christian Science Monitor, 3. June 20, 2008.

Rodiek, J. 2007. "Landscape Planning in Hazardous Zones, Lessons from Hurricane Katrina, August 2005." (Translated from English) *Landscape and Urban Planning* 79 (1): 1-4 (in English).

Schleifstein, M. "Flood Project's Cost Estimate Explodes." The Times-Picayune, 3, June 17, 2008.

Sengupta, S. "In Silt, Bangladesh Sees Potential Shield Against Sea Level Rise." New York Times, 3, March 20, 2009.

(SLO) State Land Office. 2008. "SLO Database." In *State Lands and Water Bottoms*, ed. Louisiana Department of Administration SLO (State of Louisiana, Baton Rouge, LA), Disclaimers, Metadata, Data Categories, and Downloadable GIS Data.

Society AM (2008) LSU Warns Bangladesh Ahead of Monstor Cyclone's Storm Surge. *American Meteorological Society* February 2008:1.

Titus, J.G. 1986. "Greenhouse Effect, Sea Level Rise, and Coastal Zone Management." *Coastal Zone Management Journal* 14 (3): 25.

Törnqvist, T., and Meffert, D.J. 2008. "Sustaining Coastal Urban Ecosystems." *Nature Geoscience* 1 (December 2008) :3.

Törnqvist, T. et al. 2008. "Mississippi Delta Subsidence Primarily Caused by Compaction of Holocene Strata." *Nature Geoscience* 1 (March 2008) :4.

Turner, R.E., and Cahoon, D.R. 1987. *Causes of wetland loss in coastal central Gulf of Mexico, Technical Narrative*. New Orleans, LA: U.S. Department of the Interior MMS.

Turner, R.E., and Rao C.Y. 1990. "Relationships Between Wetland Fragmentation and Recent Hydrologic Changes in a Deltaic Coast." *Estuaries* 13 (3): 10.

USDOC. 1994. *Fisheries of the United States, 1993. Current Fishery Statistics No. 9300. M. C. Holliday, O'Bannon, B.K.,* ed. National Oceanic and Atmospheric Administration NMFS. Rockville, MD.

Walsh, B. "White House opposes Morganza Levee Project." The Times Picayune, 2, April 10, 2007.

Watzin, M.C., and Gosselink M. 1992. *The Fragile Fringe: Coastal Wetlands of the Continental United States*. Louisiana Sea Grant College Program BR, LA; U.S. Fish and Wildlife Service, Washington, D.C.; National Oceanic and Atmospheric Administration, Rockville, MD.

Wayburn, L.A. 2009. "Forests in the United States Climate Policy: A Comprehensive Approach." In *Lincoln Institute of Land Policy Working Paper, 27*. Lincoln Institute of Land Policy, Cambridge, MA.

Yoachim, A. 2008. *How safe, how soon? Executive Framework, 7.* Tulane Institute on Water Resources Law and Policy. New Orleans, LA.

CHAPTER 19

Governance and Climate Change: Assessing and Learning from Canadian Cities

Christopher Gore,* Pamela Robinson, Richard Stren

1. INTRODUCTION

Canada hosted one of the first international meetings to address climate change in 1988. The *Toronto Conference on the Changing Atmosphere* helped focus the attention of national governments on the emerging international challenge presented by rising concentrations of greenhouse gases in the atmosphere. But in Canada, this event did not translate into national leadership to address climate change. While many Canadian government scientists and academics have emerged as leaders in research and international policy development, a succession of national government consultation processes and strategies since the early-1990s produced no significant national policy framework or action to reduce greenhouse gas (GHG) emissions, nor any meaningful reduction in emissions (Rabe 2007; MacDonald and Smith 1998; MacDonald 2008). In 2006, emissions in Canada were 22 percent above 1990 levels and 29 percent above Canada's Kyoto target (Environment Canada 2006a; 2006b; 2006c).

Many pragmatic reasons exist to explain why Canada has been ineffective at reducing emissions, particularly the size of the country and the associated

The authors thank Eleanor Rae and Alia Hanif for their research support on this paper.

*Corresponding author: chris.gore@politics.ryerson.ca

use of automobile and truck transportation to cover long distances, as well as its cold climate. Political and intergovernmental reasons are also significant. Canadian provinces have very diverse economic interests that affect their incentive to limit greenhouse gas (GHG) emissions. For example, Ontario's economy has been highly dependent on manufacturing and the automobile sectors, while the natural gas and oil sectors are dominant in Saskatchewan and Alberta. Meanwhile, British Columbia has independently introduced a carbon tax and Quebec has promoted climate action for some time due its reliance on hydroelectric power. Hence, provincial incentives to address climate change are diverse. Therefore, if the national government were to implement a meaningful strategy to reduce emissions it would have to address the country's pragmatic challenges and an intergovernmental scenario requiring deep compromise. No effective national climate strategy in Canada can be developed in the absence of provincial support. Yet to date, provincial interests have been too diverse and irreconcilable. Indeed, if Canadian provinces were treated as independent states, two provinces (Alberta and Ontario) would rank among the 50 largest sources of greenhouse gases in the world, followed quickly by Quebec, British Columbia and Saskatchewan (Rabe 2007).

But there is another important reason to move the discussion about Canadian climate action and policy away from a national-provincial focus: Canadian cities are national and international leaders in climate action. Yet, in spite of their initiatives, they have hardly figured in any national or provincial strategy to reduce GHG emissions (Robinson and Gore 2005; Gore and Robinson 2009; Gore 2010; Climate Group 2005). Cities have largely been taking action independent of the national government and provinces. The lack of national attention to the leadership of Canadian cities is compounded by the absence of formal municipal powers in the constitution and the absence of any national strategy to support cities generally (Bradford 2007a; 2007b).

This paper examines and explains why Canadian cities have taken action to reduce GHG emissions, while also adapting to and mitigating climate change. The paper also inventories the activities of select medium to large Canadian cities (populations between 300,000 and 2.5 million). The paper offers a simple yet unique approach to analyzing action. Action is classified as an *initiative, output* or *outcome*. **Initiatives** are policy goals that the city has made to reduce GHG emissions directly or indirectly, such as improving building efficiency. **Outputs** are the specific programs that operationalize the policy goal (initiative). **Outcomes** are results or achievements from the initiatives and outputs. The paper applies each of these categories to three dimensions of city action — land-use planning; governance; and institutions. **Land-use planning** initiatives are actions tied directly to changes in land-use such as increased density, growth management strategies, or transit and transportation. Actions under the category of **governance** are initiatives, which have a principle goal of engaging non-government organizations, the general public or the private sector in climate change or GHG emission reduction initiatives. Examples of 'governance' initiatives would be public education programs and community visioning exercises. Lastly, **institutional** actions are classified as initiatives that a municipal corporation is undertaking or are intergovernmental in character (municipal with subnational or national or inter-city or inter-municipal). Examples of institutional actions range from 'greening' municipal buildings to partnerships or collaborations with other governments.

The initiatives documented include shorter-term technical actions and medium and longer-term actions that require more complex coordination with citizens and the private sector. The goal of the chapter is to highlight how and why cities in a country with limited national leadership have chosen to act. This provides an opportunity for cities starting to initiate action, both in states that are actively engaged in national GHG emission reduction efforts and those that are not, to understand how cities in Canada have independently taken action and how future collaborations with other cities and levels of government might evolve to better mitigate and adapt to climate change.

2. LOCAL CANADIAN CLIMATE LEADERSHIP: THE CHARACTER OF ACTION

Canadian cities and municipalities are typically characterized as 'creatures of the provinces'. This is because municipalities have no recognized power in the constitution of Canada, or in national legislation, and are not legally recognized as a formal level of government. Some scholars challenge the idea that Canadian municipalities are powerless (Magnusson 2005), but on the whole, when considering municipalities and cities in Canada, the history of intergovernmental relations has been one where municipal governments — small and large — take actions only insofar as they are permitted, and have very limited capacity to challenge provincial or national policy goals. A classic example of this is the creation of the City of Toronto in 1998. The provincial government amalgamated the former City of Toronto with five surrounding municipalities despite overwhelming public opposition expressed through public meetings and a popular referendum.

With respect to climate change research and policy in Canada, the real structural and imagined weakness of Canadian municipalities remains prominent. Most historic and contemporary research and writing on Canadian national climate change policy has been silent on the role and leadership of municipalities and cities. Some esteemed Canadian urban scholars have also argued that even though Canadian cities may be active in responding to climate change, they will remain 'policy-takers not policy-makers' (Sancton 2006). Yet, despite this, both in relation to climate action and other policy areas, research suggests that this view needs careful reconsideration — municipalities can and do lead (see Pralle 2006).

2.1 Cities and Climate Action in Canada: The Scope of Action

One of the central organizations responsible for promoting the role of cities in GHG emission reductions is the Federation of Canadian Municipalities (FCM). FCM represents Canadian municipalities nationally. In the 1980s, FCM's national relevance and membership suffered owing to its engagement in prominent national political debates such as national unity (Stevenson and Gilbert 2005). In turn, in the 1990s, FCM repositioned its focus and has regained prominence and membership, in part by being more focused on specific policy issues that resonate with municipalities nationally and that are not so divisive, such as calls for national funding of city infrastructure and transit. One area that FCM has been particularly active is in the promotion of 'sustainable communities'. The Partners for Climate Protection Program (PCP) is one aspect of this focus. The PCP program helps municipalities reduce corporate and community greenhouse gas emissions through knowledge sharing and grants. In 2011, over 78% of Canadian citizens resided in a municipality that had made a formal commitment to inventory and take action to reduce GHG emissions under the PCP program (FCM 2009). This commitment is formalized by a city council's agreement to join. Cities that participate in the PCP program agree to work to reduce GHG emissions in corporate operations 20% below 1994 levels, and 6% below 1994 levels throughout the community within ten years of joining.

FCM's PCP program parallels the International Council for Local Environmental Initiatives (ICLEI) Cities for Climate Protection Program (CCP). Prior to partnering with ICLEI to create the PCP program, FCM had its own emissions reduction program called the '20% Club', which started in 1995 - members committed to reduce their corporate emissions 20 percent below 1994 levels. Given that ICLEI's international headquarters used to be in Toronto, it was a natural extension for Toronto and other Canadian cities to be early leaders in emission reduction efforts and to work with the international body.

As of March 2010, 200 municipalities representing every province and territory in Canada were members of the PCP program; many have been members for a decade or longer. Table 1 lists participation by province and territory.

TABLE 1
PCP Members by Province and Territory (March 2010)

Province/Territory	Number of Participants
Alberta	16
British Columbia	61
Manitoba	20
New Brunswick	17
Newfoundland	7
Northwest Territories	3
Nova Scotia	13
Nunavut	1
Ontario	48
Prince Edward Island	2
Quebec	9
Saskatchewan	2
Yukon	1
Total	200

In 2006, a majority of Canada's largest municipalities were also PCP members — 36 of 50. This figure, in addition to the high level of urbanization in Canada, helps to partly explain why such a large proportion of Canada's population lives in a municipality committed to GHG reductions. Table 2, provides a list of the 50 largest municipalities by population in 2006, the status of their membership, when they joined, and what milestones they have completed in the PCP and ICLEI five milestone system of action as of March 2010. It is important to note that data on milestones is derived from municipal self-reporting. Therefore, if a municipality has not updated its progress with FCM, FCM would not present this. This presents problems relating to the reliability of municipal performance and the ability to compare city performance. For example, according to Toronto's own records, it has completed all of FCM's milestones. However, FCM does not record this. The information in Table 2 is derived from FCM.

TABLE 2
Fifty Largest Canadian Municipalities and Participation in FCM's Partners for Climate Protection (PCP) Program (FCM reporting)

Municipality	Province	Population 2006	PCP Member Date Joined	Corporate Milestones 2010	Community Milestones 2010
1. Toronto	Ont.	2,503,281	1990	3	3
2. Montreal	Que.	1,620,693	September 1998	3	1
3. Calgary	Alta.	988,193	1994	5	4
4. Ottawa	Ont.	812,129	February 1997	4	4
5. Edmonton	Alta.	730,372	1995	5	5
6. Mississauga	Ont.	668,549	December 1999	3	2
7. Winnipeg	Man.	633,451	November 2006	4	1
8. Vancouver	B.C.	578,041	1995	4	4
9. Hamilton	Ont.	504,559	November 1996	2	2
10. Quebec	Que.	491,142	January 1997	3	3
11. Brampton	Ont.	433,806	NO	-	-
12. Surrey	B.C.	394,976	July 1996	1	1
13. Halifax	N.S.	372,679	February 1997	4	3
14. Laval	Que.	368,709	March 1997	3	3
15. London	Ont.	352,395	November 1994	4	4
16. Markham	Ont.	261,573	February 2007	0	0
17. Gatineau	Que.	242,124	NO	-	-
18. Vaughn	Ont.	238,866	NO	-	-
19. Longueuil	Que.	229,330	NO	-	-
20. Windsor	Ont.	216,473	December 2002	1	1
21. Kitchener	Ont.	204,668	January 1997	0	0
22. Burnaby	B.C.	202,799	November 1994	1	1
23. Saskatoon	Sask.	202,340	December 2004	3	2
24. Regina	Sask.	179,246	1994	3	3
25. Richmond	B.C.	174,461	June 2001	1	1
26. Oakville	Ont.	165,613	June 2004	2	2
27. Burlington	Ont.	164,415	June 2002	1	1
28. Richmond Hill	Ont.	162,704	September 2000	3	3
29. Greater Sudbury	Ont.	157,857	1997	4	4

TABLE 2, *continued*

Municipality	Province	Population 2006	PCP Member Date Joined	Corporate Milestones 2010	Community Milestones 2010
30. Sherbrooke	Que.	147,427	NO	-	-
31. Saguenay	Que.	143,692	NO	-	-
32. Oshawa	Ont.	141,590	April 2009	0	0
33. St.Catherines	Ont.	131,989	NO	-	-
34. Levis	Que.	130,006	NO	-	-
35. Barrie	Ont.	128,430	March 2001	2	2
36. Trois-Rivères	Que.	126,323	NO	-	-
37. Abbotsford	B.C.	123,864	June 2002	1	1
38. Cambridge	Ont.	120,371	NO	-	-
39. Kingston	Ont.	117,207	April 2001	2	2
40. Guelph	Ont.	114,943	April 1998	2	2
41. Coquitlam	B.C.	114,565	March 1997	1	1
42. Whitby	Ont.	111,184	NO	-	-
43. Thunder Bay	Ont.	109,140	March 1997	3	3
44. Saanich	B.C.	108,265	July 1996	1	2
45. Chatham-Kent	Ont	108,177	NO	-	-
46. Kelowna	B.C.	106,707	January 2001	1	0
47. Cape Breton	N.S.	102,250	NO	-	-
48. St. John's	N.L.	100,646	January 2001	3	3
50. Waterloo	Ont.	97,475	June 1999	0	0

2.2 Canadian Cities and Climate Change: Explaining Action

In 1998, the Canadian federal government launched a national climate consultation process. The process established sixteen expert sector 'tables' to examine the impacts of climate change and to identify actions each sector may take to reduce greenhouse gas emissions as it moved towards a national implementation strategy. One of the expert tables created was a 'municipalities table'.

In its final report, the Table advanced a remarkable observation: municipalities in Canada directly or indirectly control or influence more than 50% of national GHG emissions (Municipalities Table 1999). This calculation was later reconfirmed by an independent source (Robinson 2000). The report also noted that the facilities, infrastructure, lands and resources of municipalities are at considerable risk from climate change — an observation consistently reinforced by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2007). The Municipalities Table stated categorically: "…municipal governments have been leaders in recognizing the issue of climate change, in identifying opportunities for action, and in implementing initiatives and programs. Many are prepared to play an active role as a contributing partner to a national GHG reduction initiative" (Municipalities Table, 1999; 2-3).

Despite this decade-old proposition, and the significant volume of national emissions municipalities influence, successive Canadian federal governments have not seriously engaged cities and municipalities as active partners in climate action. This is not to say that the federal government has entirely ignored the national role municipalities play in the well-being and maintenance of infrastructure and the environment. FCM received a large, one time cash contribution ($300 million) from the former federal Liberal government in 2005 to advance community sustainability goals. In 2008, the federal Conservative government also made a municipal share of the federal gas tax permanent. These actions, however, will not reduce the infrastructure deficit cities in Canada confront (Slack and Bird 2007) and do not represent specific or consistent efforts to work with cities to develop a collaborative, intergovernmental strategy to reduce GHG emissions. In this light, it is important to understand why cities in Canada have taken action largely independent of other levels of government.

In 1999, Robinson surveyed municipal staff responsible or potentially responsible for GHG emission reductions in all Canadian municipalities with a population over 10,000 — 392 in total (Robinson 2000). The survey aimed to document what action municipalities were taking and what were the barriers to action. With a response rate of 60.3%, an important window into the motivation for action was revealed. Respondents were classified as either No-Action or Action municipalities. For municipalities that had not taken action, a number of barriers were acknowledged, including that climate change was not an issue for local government and/or was a federal government issue; it was not a priority for Council; it was difficult to address at the local level; and staff lacked training, time and financial resources (Robinson and Gore 2005). Municipalities that were taking action also acknowledged many of these barriers, but also revealed important reasons for action that have been confirmed by other research (Lindseth 2004; Bulkeley and Betsill 2003; Zharan 2008).

First, in relation to participation in a global community or network of other actors, cities are motivated to take action because it is deemed to make an important global contribution. Cities also take action due to genuine citizen support, encouragement and collaborations with citizens. Pragmatically, actions to reduce GHG emissions are also deeply connected to other goals and co-benefits such as human health improvements through improved air quality, cost savings, adaptability to real or potential vulnerabilities due to climate change, and overall improvements in short, medium and long-term urban sustainability. Common programs aimed to achieve multiple benefits, including GHG reductions, are: changes in building codes and standards; 'greening' of corporate operations; landfill gas capture; promotion of public transit and non-automobile transportation; and changes in land-use.

These types of climate actions are common to North American municipalities but they do not illustrate the specific activities individual cities have taken, nor whether some actions are more commonly used. Do corporate emission reduction strategies dominate municipal action or are municipal leaders reaching out to work with citizens, businesses, and other levels of government in an effort to reduce emissions collectively? Are cities making efforts to address the more vexing contributions to climate change that are tied to human behavior and lifestyle preferences? That is, are cities confronting land-use issues such as automobile-oriented, low-density residential development (Robinson 2006; Robinson 2009; Bailey 2007)? Given that many Canadian cities are recognized as national and international leaders in climate action and have been engaged in this action for many years, the next section inventories the initiatives, outputs and outcomes of a range of medium to large Canadian cities along three dimensions of climate action: institutional, governance and land-use planning. This inventory provides lessons about what actions cities in Canada have deemed administratively and politically possible opening up the opportunity for other cities to learn from this experience.

3. INVENTORY OF LAND-USE PLANNING, GOVERNANCE AND INSTITUTIONAL ACTIONS: A SELECTION OF MEDIUM TO LARGE CITIES IN CANADA

In the proceeding pages, the climate-related institutional, land-use planning, and governance actions of eight Canadian cities are inventoried: Vancouver, British Columbia; Calgary, Alberta; Edmonton, Alberta; Winnipeg, Manitoba; Ottawa, Ontario; Toronto, Ontario; Montreal, Quebec; and Halifax, Nova Scotia. Table 3 summarizes some of the prominent climate-related information of each city, and also notes the population growth rate for each city from 2001 to 2006. The cities are not randomly selected. The cities represent medium to large Canadian cities across the country that have demonstrated some leadership in climate action. It is also noteworthy that with the exception of Winnipeg, each city has been a member of FCM's Partners for Climate Protection (PCP) program for over ten years. Many municipalities, some less than 1,000 people, are also members of the PCP program. But in the interest of trying to draw lessons from Canadian cities that are relevant to other cities in the world it was deemed more appropriate to inventory cities of a medium to large size as it is more likely that larger cities will have the capacity and resources to undertake mitigation activities. We recognize that this limits the applicability of lessons in Canada, given that Canadian cities have not made adaptation to climate change a high priority, whereas this will be a central priority in many cities in the global south.

TABLE 3
Profile of Eight Medium to Large Canadian Cities

Municipality	Province	Population 2006	Population Increase (2001 to 2006)	PCP Member Date Joined	Corporate Milestones	Community Milestones
Toronto	Ontario	2,503,281	0.9%	1990	3	3
Montreal	Quebec	1,620,693	2.3%	September 1998	3	1
Calgary	Alberta	988,193	12.4%	1994	5	4
Ottawa	Ontario	812,129	4.9%	February 1997	4	4
Edmonton	Alberta	730,372	9.6%	1995	5	5
Winnipeg	Manitoba	633,451	2.2%	November 2006	4	1
Vancouver	British Columbia	578,041	5.9%	1995	4	4
Halifax	Nova Scotia	372,679	3.8%	February 1997	4	3

Tables 4 through 11, document the host of initiatives undertaken by these eight cities, the outputs of these initiatives, and where information was available, the outcomes. With the exception of Toronto, this information is derived from secondary sources and from general knowledge of the authors. The tables illustrate that each city has developed some unique, city-specific initiatives, particularly in relation to efforts to reach out to citizens. These 'governance' initiatives, however, do not represent a common and dominant approach to climate change in Canadian cities.

The strongest similarity between cities is that the first priority action is to reduce corporate emissions. Indeed, 'technical fixes' are responsible for reducing corporate emissions most quickly and most dramatically in a short period of time (Robinson 2006). Hence, when scanning the institutional actions of cities, most are engaged in activities relating to building and/or lighting energy improvements and landfill gas capture. The reasons for embracing corporate, institutional actions are straightforward: they require minimal or no community buy-in, creating little political debate; they usually produce direct returns with respect to cost savings; they produce quick, verifiable reductions in emissions; and actions to reduce corporate emissions are promoted as important first steps by ICLEI and FCM. For example, in 1990, 72% of Toronto's GHG emissions were from methane gas generated by landfill sites and the waste collection system (Climate Group 2005). Through a landfill gas capture program at one site, the city is able to generate about 44 MW of electricity, an annual reduction of 1 million tons of CO2 equivalent, and annual revenues in excess of $2 million (Environment Canada 1999; Climate Group 2005). With respect to other institutional activities, all leading cities are members of FCM's PCP program, inevitably providing incentives and knowledge to execute activities. What is not evident with respect to institutional action is the presence of clear, specific collaboration with provincial or federal governments. As earlier noted, while infrastructure and transit funding is provided by the federal and provincial governments, no constructive process has been established to share the burden of response to climate change between levels of government.

The two other dimensions analyzed are governance and land-use planning initiatives. From a governance perspective, many cities are advancing innovative efforts to work with citizens and communities. In most cases, however, these efforts have come about after undertaking corporate actions. The logic of this sequencing is intuitive: cities must address their own challenges and demonstrate independent leadership before reaching out to the community and it is easier for cities to get their own proverbial emissions house in order before turning to the community. Two reasons help explain the move to build relations with the community. First, once cities have undertaken or demonstrated efforts to undertake climate action through technical changes, ongoing and continued reductions will be difficult to achieve without addressing how humans use energy and burn fuel – factors tied to consumption patterns and lifestyle. Second, citizen awareness of and interest in addressing climate change continues to be strong, even in the midst of the global recession. A 2008 poll revealed that 83% of Canadians agreed, "Canada should commit to strong action on global warming without waiting for other countries" (Pembina 2009). At the same time, poll results about what Canadians are willing to individually do to address climate change are mixed, with some suggestions that citizen willingness to make sacrifices has diminished over time. Either way, if cities are taking action, it is likely that they will try to tap into the climate consciousness of citizens, particularly through education programs and engagement activities. These two factors seem to also be influential for cities that have more recently come to embrace climate action, such as Winnipeg, which appears to be reaching out to community members earlier on than other Canadian urban leaders.

Finally, one of the areas that cities in Canada do not appear to be prioritizing for action is in land-use planning. While some cities have implemented tree-planting activities and several are pursuing improvements in public transit infrastructure, few cities are directly identifying the emission reduction benefits of growth management and increased density. Calgary, Vancouver, and Toronto — all prominent climate leaders in Canada — are examples of cities that are making explicit connections between land use and emissions. However, the majority of cities investigated have few if any specific initiatives making these connections. Two reasons can be offered for this: 1) most provinces have final oversight over land use planning, and, therefore, cities may have to navigate a difficult legal intergovernmental quagmire if they want to significantly amend long-range planning, or they may be waiting for provinces to lead in this area; 2) the promotion of densification and reductions in car dependency in Canada are extraordinarily divisive policy areas, which openly challenge the preference for and legacy of suburban development in most Canadian cities. Therefore, efforts to challenge land-use preferences in the name of climate change will inevitably be one of the most difficult actions city governments take in future.

In the subsequent tables land-use planning initiatives are identified first, followed by governance initiatives and then institutional initiatives. 'NA' indicates that the information was 'not available'. The cities are presented starting in western Canada, Vancouver, and moving eastward to Halifax.

TABLE 4
Vancouver, British Columbia's Land-Use, Governance and Institutional Climate Actions

Land-Use Planning – Initiatives	Land-Use Planning – Outputs	Land-Use Planning – Outcomes
Eco-Density	- Applications for re-zoning must meet LEED Silver certification - Sites greater than 2 hectares seeking rezoning must meet new sustainability performance criteria - New priority areas: laneway housing; basement apartments and removal of barriers to green building	NA
Transportation alternatives	- Vancouver Transportation Plan and the Downtown Transportation Plan - Translink's 10-year Outlook: expanding transit services; - U-Pass, Sky Train expansion, B-Line and Community Shuttle bus service (helping the shift from drivers to transit users); - Streetscape Amenities program: racks and lockers, bike stations, information about bicycle parking, converting parking spaces to bike parking, etc. - Way to Go School program and Off-Ramp: sustainable transportation practices for school travel	NA
Governance – Initiatives	**Governance – Outputs**	**Governance – Outcomes**
Community engagement	Expanding and applying existing community programs such as Way to Go, Action Schools, Cool Schools, BOMA's "Go Green" Program, etc.	NA

TABLE 4, *continued*

Institutions – Initiatives	Institutions – Outputs	Institutions – Outcomes
Participation in FCM Partners for Climate Protection (PCP) Program	NA	NA
Building efficiency	Energy Performance Contracts (EPCs): retrofitting buildings;	NA
Vehicle and fuel efficiency	Idle-free program, supporting efficient vehicle operations and maintenance,	NA
Landfill gas recovery	Vancouver Landfill Gas Recovery and Cogeneration Project	Between 2000 and 2003, Vancouver implemented a large-scale landfill gas recovery and co-generation project that reduced GHG emissions by 75% (200,000 tonnes per year) while also generating electricity to power 11,000 homes and a nearby greenhouse
Streetlights and traffic lights retrofitting	Replacing incandescent lights with LED and low-wattage compact fluorescent bulbs	Electricity used for street lighting decreased by 24% from 1990 to 1999 due to evolutions in lighting technologies. The City predicted another 29% decrease between 1999 and 2010
Corporate demand-side management	Improving commuter choices and energy usage behaviours: implementing a Coordinator-Civic Employee Sustainability Program	NA
Residential energy efficiency	Energuide for Existing Housing (EGH) program: assessing home energy performance and finding opportunities for energy savings; use of federal grants and financial incentives	NA
Commercial and new building efficiency	Use of the LEED rating and auditing system in construction of new buildings and retrofitting	NA
Corporate fleet	Right-sizing vehicles, equipment replacement programs, shift to alternatively-fuelled and electric vehicles, fleet demand management, hybrid technologies, carpooling,	NA
Corporate waste reduction and landfill gas recovery		NA
Corporate building efficiency	- Energy Performance Contracts (EPCs) that may include: Interdepartmental energy committees; Savings sharing funds - Energy Efficient Purchasing Policy: use of EnergyStar products, reducing electrical consumption, etc.	NA

Sources, Vancouver: City of Vancouver, "EcoDenisty". April 19, 2009. Available at: http://www.vancouver-ecodensity.ca/; Cool Vancouver Task Force, "The Climate-Friendly City: Community Climate Change Action Plan: Creating Opportunities." March 29, 2005. Available at: http://www.sustainablecommunities.fcm.ca/Partners-for-Climate-Protection/milestones/British-Columbia.asp.

TABLE 5
Calgary, Alberta's Land-Use, Governance and Institutional Climate Actions

Land-Use Planning – Initiatives	Land-Use Planning – Outputs	Land-Use Planning – Outcomes
Plan-it Calgary	Integrated landuse and mobility plan; intended to align with the 100-year imagineCALGARY sustainable community plan.	NA
Support of public transit	Hertz car rental discount to customers with a transit pass	NA
Transportation improvements	Car Heaven program: recycle your old car and get a 6 month transit pass or $1000 towards a new vehicle	Transportation improvements
Governance – Initiatives	**Governance – Outputs**	**Governance – Outcomes**
Fostering civic partnerships; Encouraging technology deployment	Energy Management Office (EMO)	NA
Residential water conservation	Water Saver Kits; Toilet Rebate Replacement Programme; Public Education; Water Utility By-Law for new buildings	NA
Creating a community vision for Calgary	imagineCalgary project: creating a 100-year sustainability plan for the city of Calgary	NA
Climate Change awareness	'Climate Change and You' newsletter and information sheets, sent out by the City of Calgary	NA
Decreasing residential energy use consumption	Energy Star furnace replacement and washer rebate programs	NA
Reducing commercial energy use consumption	Building Owners and Managers (BOMA) Go Green Program	NA

TABLE 5, *continued*

Institutions – Initiatives	Institutions – Outputs	Institutions – Outcomes
Participation in FCM Partners for Climate Protection (PCP) Program	NA	NA
Energy efficiency of city buildings	Energy Performance Contracting (EPC) programs: partnerships between the City and private energy firms. The financial rewards reaped from better energy efficiency are repaid to the energy service company over a ten year contract	After project completion in 2004, the following City buildings had been improved: the Calgary Fire Department; Manchester Yards; Transportation facilities; the ENMAX/Alberta Trade Centre; and the Corporate Properties Group and Waste and Recycling Services buildings. Also, it is estimated that the EPC program continues to deliver about 30 kt in annual greenhouse gas emission reductions.
"Green Power" energy options	Ride-The-Wind program: partnering with the City's electricity supplier, ENMAX Power Corporation to power local transit with energy from windmills	The Light Rail System (LRT) is powered entirely by green power ; the programme also includes a commitment from ENMAX Power Corporation to provide 90% green power
Data Collection System	greenHouse gas Emissions & Abatement Tracking (HEAT): annual reporting of corporate GHG emissions	NA
Sustainable Building Policy	Policy: All new buildings in excess of 500m^2 must meet or exceed the silver level of the LEED (Leadership in Energy and Environmental Design) rating system. (Ratings are Certified, Silver, Gold and Platinum).	As of the 2006 report, two facilities using the LEED rating system had been built (Crowfoot Library and Cardel Place) and two were under construction (the Water Centre and the Country Hills Multi-Service Centre)
Landfills: methane gas emission reduction	Waste diversion and methane capture projects, Biocap pilot project, wastewater capture at Bonnybrook Wastewater Treatment Plant, etc.	NA
Streetlight and traffic signal retrofitting	EnviroSmart Streetlight Retrofit and LED Traffic Signal replacement programs: replacing streetlights with lower-wattage and flat lens fixtures, replacing incandescent lights at traffic signals with LED lights	- As of 2003, about 20,000 (of a total of 37,500) streetlights had been retrofitted, providing the city with about \$1.7 million per year in energy cost savings - As of 2003, over a third of the 730 intersections in Calgary with incandescent lights had been replaced. Electricity savings to the city are at just under \$700,000 per year

Source, Calgary: The City of Calgary Environmental Management, "Calgary Climate Change Action Plan Target 50: The City of Calgary Corporate and Community Outlook on Climate and Air Quality Protection." July 2006. Available at: http://www.sustainablecommunities.fcm.ca/Partners-for-Climate-Protection/milestones/Alberta.asp

TABLE 6
Edmonton, Alberta's Land-Use, Governance and Institutional Climate Actions

Land-Use Planning – Initiatives	Land-Use Planning – Outputs	Land-Use Planning – Outcomes
NA	NA	NA
Governance – Initiatives	**Governance – Outputs**	**Governance – Outcomes**
Energy efficiency awareness	CO_2RE memberships: free to sign up for newsletters, special promotions, etc.	Website and call-in contact line, newsletters and how-to publications and training packages
Partnerships between the city, NGOs and private sector	CO_2RE (Carbon Dioxide Reduction Edmonton) organization: team members represent various organizations such as ATCO Gas, EcoCity, Sierra Club, Toxics Watch Society, Urban Development Institute, Worthington Properties, etc.	NA
Institutions – Initiatives	**Institutions – Outputs**	**Institutions – Outcomes**
Participation in FCM Partners for Climate Protection (PCP) Program		NA
Participation in the Voluntary Challenge and Registry (VCR) since 1995		NA
Retrofitting existing buildings	At least 21 projects, funded by the Energy Management Revolving Fund	NA
Transit	Implementing hybrid buses	NA
Wastewater treatment	Conversion of Gold Bar's aeration system to Fine Bubble in 2001	NA
Municipal Fleet	Fuel Sense Program	NA

Sources, Edmonton: CO2RE. Online: www.co2re.ca; City of Edmonton, "Corporate Greenhouse Gas Emissions Reduction Action Plan," Dec 23 2004. Available at: http://www.sustainablecommunities.fcm.ca/Partners-for-Climate-Protection/milestones/Alberta.asp

TABLE 7
Winnipeg, Manitoba's Land-Use, Governance and Institutional Climate Actions

Land-Use Planning – Initiatives	Land-Use Planning – Outputs	Land-Use Planning – Outcomes
Transportation	- "Smart Driving" program (fuel-efficient driving techniques courses) - Active Transportation Study: outlining the interests, gaps, vision for transportation and comparisons to other North American cities (looks at public transport services, cycling services, pedestrian services, etc.)	See Active Transportation Study at http://winnipeg.ca/interhom/greenspace/
Governance – Initiatives	**Governance – Outputs**	**Governance – Outcomes**
Partnerships with green agencies	Membership in the Manitoba Chapter of the Canada Green Building Chapter	NA
Awareness and education campaigns; individual actions	Pembina Trails School Division multi-year program focused on no/low-cost energy solutions (energy conservation in classrooms; encouraging students to create and implement energy-saving measures)	NA
Transportation efficiency partnerships	Red River Valley Clean Cities Coalition (RRVCCC) Winnipeg Chapter: voluntary partnership between government, business, non-profits, and post-secondary institutions aiming to reduce idling, promote alternative fuels, vehicles, etc.	NA
Reduction of water consumption	"Slow the Flow" program: Department of Water and Waste partnering with Fort Whyte Centre to provide a water efficiency youth education program; focus on long-term water consumption reduction	City's LCD (litres per capita per day) has dropped almost 30% since 1990 levels (a trend likely to continue)
Communication	Environmental promotion website on City's official site: containing information, tips, alternatives, updates, etc.	http://winnipeg.ca/interhom/greenspace/ www.climatechangeconnection.org

TABLE 7, *continued*

Institutions – Initiatives	Institutions – Outputs	Institutions – Outcomes
Participation in FCM Partners for Climate Protection (PCP) Program	NA	NA
Streetlights and Traffic Signals	Updating with LED systems	- As of July 31, 2006, the Department of Public Works had installed about 5,950 LED systems out of a total of 18,700 units - By October 207, 41.73% of all traffic signal displays had been replaced, with a total savings of over 2.2 million kilowatt hours of electricity[1]
Landfill methane gas recapturing	Brady Road Landfill project	NA
Civic Vehicle Fleet	Winnipeg Fleet Management Association (WFMA) works to reduce size of city's fleet, shift towards hybrid vehicles and alternative fuels, prevent idling. (e.g. Health Communities Don't Idle campaign/voluntary Idle Free Zones signposts)	- Fleet has been reduced by about 30%, from over 2300 vehicles to under 1600. 12 hybrid vehicles have been incorporated into the fleet (as of July 2007) - Idle free zones posted at various civic sites; City of Winnipeg has committed to creating an Idle Free Administrative Directive for idling guidelines for the city's fleet
Upgrading civic facilities	Partnership with Manitoba Hydro to enhance efficiency of city buildings	e.g. 2 swimming pools have had solar panels installed, etc.
Building energy efficiency and retrofitting	PowerSmart projects; LEED standards adopted	e.g. retrofitting of Pan Am Pool complex, a project that reduced GHG emissions by approximately 46 tonnes

Source, Winnipeg: City of Winnipeg. "Active Transportation Study" Available online: http://winnipeg.ca/interhom/greenspace/

[1]The City of Winnipeg, "Climate Change Action Plan: Quaterly Report – October 2007). Available online: http://winnipeg.ca/Interhom/GreenSpace/ClimateChange.stm

TABLE 8
Toronto, Ontario's Land-Use, Governance and Institutional Climate Actions

Land-Use Planning – Initiatives	Land-Use Planning – Outputs	Land-Use Planning – Outcomes
Official Plan (long range policy document)	Land use intensification and transit-oriented design	NA
Encourage green economic development clusters.	Emphasis on renewable energy cluster and sustainable design cluster	NA
Governance – Initiatives	**Governance – Outputs**	**Governance – Outcomes**
Transit City plan	In collaboration with Toronto Transit Commission and funded by Metrolinx (regional transportation planning authority) new investment in public transit infrastructure	Seven new light rail lines to be built by 2015.
Local food procurement	Require city-run facilities to purchase a certain % of food from local producers; require all large food retailers to indentify food kilometers on 10 commonly eaten produce items;	NA
Energy conservation and renewable energy	Expand and continue all Toronto Hydro programmes to support energy efficiency and conservation	NA
LiveGreen Toronto	City's initiative to engage local residents in a range of activities to reduce GHGs.	http://www.toronto.ca/livegreen/index.html, community grants being made to support activities
Better Buildings Partnership	Using a revolving loan fund, the BBP provides loans to public, private and institutional building owners to complete building energy and water retrofits; the loan is repaid using the reduction in utility bills over a fixed repayment schedule.	By 2007, 636 buildings were registered; 47 million ft^2 of floor area was retrofitted floor; 2,530 person years of jobs created, estimated $161 million in economic impact and annually 194,500 tonnes of CO2 were reduced.
Institutions – Initiatives	**Institutions – Outputs**	**Institutions – Outcomes**
Building energy efficiency and retrofitting	Retrofit of 50% of single family homes and small businesses by 2020; finance mechanism developed for high density building retrofit; procurement of renewable energy on City owned properties; mandatory green building standards by 2012; cut small engine use by 50% by 2020; eliminate use of all incandescent bulbs in City's buildings; conversion of street lighting to LED by 2020; reduce electricity used for water treatment by reducing water consumption by 50% by 2020; expand deep lake cooling to meet 90% of space cooling needs on waterfront and downtown by 2020; conserve 90 MW electricity by 2012	NA
Fuel conversion	City fleet conversion to biodiesel by 2015; require haulage firms within city to use biodiesel	NA
Clinton Climate C40 Climate Leaders Group	Network to expand capacity of cities to reduce GHG emissions	NA
Landfill gas capture	Expand methane collection at additional landfills	Landfill gas capture at Keele Valley Landfill has resulted in 149,000 tons of CO2 offset as a result of not having to use coal to produce electricity; and a capture of 1.8 million tons of methane.
Renewable energy	Fulfill 25% of energy demand in Toronto urban area by 2020	NA
Urban greening	Double existing tree canopy to 34%	NA

Sources, Toronto: Toronto Transity Commission. "TTC Transit City". April 20, 2009. http://www3.ttc.ca/About_the_TTC/Projects_and_initiatives/Transit_city/index.jsp; Toronto Better Buildings Partnership, http://www.toronto.ca/bbp/; Clinton Climate Initiative. www.c40cities.org/; http://www.c40cities.org/bestpractices/waste/toronto_organic.jsp

TABLE 9
Ottawa, Ontario's Land-Use, Governance and Institutional Climate Actions

Land-Use Planning – Initiatives	Land-Use Planning – Outputs	Land-Use Planning – Outcomes
Sustainable land-use planning and community greening	Greenspace Master Plan and the Official Plan for the City of Ottawa: concentration on compact development and mixed zoning, carbon sinks through tree-growing programs	NA
Transportation improvements	Transportation Demand Management (TDM) and the Transportation Master Plan (TMP): investing in the accommodation of walking, cycling, transit capacity and service; investing in rapid transit and intelligent transport system that can forecast and improve transit flow. Other strategies include: anti-idling campaigns, International Walk to School Day, Car Free Day, TravelWise Awards, Eco-pass, etc.	NA
Governance – Initiatives	**Governance – Outputs**	**Governance – Outcomes**
Promoting residential sector energy efficiency	Envirocentre Partnership, part of the federal Energuide for Houses program	Based on an average GHG reduction of 3 tonnes per household, the program has the potential of reducing 10,000 tonnes of GHGs
Energy efficiency improvements	Local Improvement Charges through the Pembina Institute	NA
Energy and water efficiency awareness	Employee Energy Efficiency Program: an internal program for City employees designed to increase efficiency at home and in the workplace	NA
Smog management	Smog Action Plan	NA
Institutions – Initiatives	**Institutions – Outputs**	**Institutions – Outcomes**
Participation in FCM Partners for Climate Protection (PCP) Program	NA	NA
Green Buildings	LEED ratings system and ASHRAE promotion	NA
Waste management	Integrated Waste Management Master Plan (IWMMP): focus on waste diversion, reducing packaging, landfill gas utilization and green procurement	NA
Alternative energy and community energy planning/conservation programs	Efficient appliances, reduction of water use, district energy, renewable energy, and co-generation	NA
Air quality management	Winter Air Quality programs; Smog Alert programs; Noise and odours; Street Cleaning and Pollen reduction measures	NA
Landfill gas co-generation	Partnership between the City and Energy Ottawa to heat between 5000 and 6000 homes from the Trail Road and Nepean landfill sites	NA
Water efficiency	Outdoor Water Use Strategy, Non-Revenue Water Strategy, Indoor Water Use Strategy, Education and Awareness Strategy, Monitoring and Reporting Strategy	NA
Streetlight and traffic signal retrofitting		NA
Reduction of building energy use in industrial, commercial, and institutional sectors	Better Buildings Partnership: using proven technologies to conserve energy through promotions and financial incentives. Stakeholders from community groups, home owners, home heating oil companies, industry, commerce, etc.	NA
Transportation improvements	Fleet Emissions Reductions Strategy (FERS):	NA

Source, Ottawa: Air Energy Initiatives, Environmental Management Division, Planning and Growth Management Department, "Air Quality and Climate Change Management Plan for the City of Ottawa." November 2004. Available at: http://www.sustainable-communities.fcm.ca/Partners-for-Climate-Protection/milestones/Ontario.asp

TABLE 10
Montreal, Quebec's Land-Use, Governance and Institutional Climate Actions

Land-Use Planning – Initiatives	Land-Use Planning – Outputs	Land-Use Planning – Outcomes
Transportation and Air Quality	- Transportation Plan (2005) - By-law and public awareness about vehicle idling - Reducing illegal outdoor parking spots in city centre - Minimize traffic on Mount Royal - Promote car sharing - Enhance cycling infrastructure (Montreal-wide cycling network) - Promote sustainable transport through the workplace (public transport, carpooling, biking, walking, etc.) - Replace city's 500 sub-compact automobiles with energy efficient vehicles - Replace 106 six-cylinder gasoline engine vans with four-cylinder engine vans (by 2011) - Implement compensation mechanisms for carbon-neutral business travel	- By-law about idling has been passed; needs follow-up on enforcement and awareness
Reducing Greenhouse Gas Emissions/Improving Air Quality	- Tree Policy	NA
Governance – Initiatives	**Governance – Outputs**	**Governance – Outcomes**
Residential Environments	- Support the Quartiers 21 Projects: support financially at least 2 new locally innovative environmental projects and one project that follows Montreal's Integrated Urban Revitalization projects - Multiply contact points with water (create at least 5 new contact points along riverbanks, parks, etc.) - Reduce urban heat islands (greening strategy, downtown green projects) - Promotion of urban agriculture	NA
Encouraging sustainable development practices in industry and business	Industrial design contest to reduce quantity of waste treated	NA
Biodiversity and protection of natural resources	Sign a partnership agreement with the Secretariat of the Convention on Biological Diversity	NA
Public participation and mobilization	Public Consultation and Participation Policy	NA
Residential Environments	2007-2010 Cleanliness and Maintenance Plan: putting emphasis on coalitions of partners, businesses, community organizations, etc; communications campaign to accent the civic role and responsibility of the Montreal resident; education and awareness education programs	NA
International contribution to sustainable development	- Become a United Nations University regional expertise centre for education on sustainable development	NA
Institutions – Initiatives	**Institutions – Outputs**	**Institutions – Outcomes**
Participation in FCM Partners for Climate Protection (PCP) Program		
Commitment to Sustainable Development Plan	- Organizations committing themselves to achieving one or more of the actions in the Sustainable Development Plan report (encouraged to complete 5 actions, with at least one feature action)	By late 2006, over 70 organizations had committed to performing actions from the start-up phase (2005-2006) plan. In early 2007 these organizations were asked to extend their performance in keeping with the redefined 26 actions outlined in the 2007-2009 Phase report
Waste management	- Metropolitan Waste Management Plan (PMGMR)	NA
Energy efficiency of buildings	- Updating and construction energy efficient municipal buildings	Energy efficiency of buildings

Source, Montreal: City of Montreal. "Montreal's First Strategic Plan for Sustainable Development: 2007-2009 Phase." Available at: http://ville.montreal.qc.ca/developpementdurable

TABLE 11
Halifax, Nova Scotia's Land-Use, Governance and Institutional Climate Actions

Land-Use Planning – Initiatives	Land-Use Planning – Outputs	Land-Use Planning – Outcomes
NA	NA	NA
Governance – Initiatives	**Governance – Outputs**	**Governance – Outcomes**
Energy efficiency and climate change awareness	Naturally Green newsletter – available online	NA
Institutions – Initiatives	**Institutions – Outputs**	**Institutions – Outcomes**
Participation in FCM Partners for Climate Protection (PCP) Program	NA	NA

Source, Halifax: Halifax Regional Municipality, " Welcome to Naturally Green." http://www.halifax.ca/environment/index.html

4. CONCLUSION: LESSONS LEARNED FROM CANADIAN CITIES

This paper began by acknowledging an important yet poorly understood phenomena in Canada: despite the lack of climate change action on the part of the national government and provincial governments, Canadian cities are leaders in climate-related initiatives and GHG emission reductions. Indeed, the City of Toronto's Better Buildings Partnership program — a program it pioneered — now serves as a model for the C40, Clinton Climate Initiative. In Canada, this leadership suggests that response to climate change should not be treated like other policy areas in the federation. Debate about 'who should do what' is misplaced, will only fuel further intergovernmental tensions, and will not succeed in producing a comprehensive national strategy to address climate change. Hueglin's call (2007) to consider 'how much of what' each level of government, including municipal institutions, should do is particularly important and appropriate for future climate change action. This parallels the arguments of some urban scholars who have identified the need for 'interscalar coordination', whereby local policy action must be integrated into broader social and economic policies (Bradford 2007b). Coordination is important. The climate actions of cities in Canada and globally should not serve as a reason for subnational and national governments not to act. Instead, these actions put the onus on subnational and national governments to support and conform with the leadership of cities, and to take initiatives in areas where cities cannot lead or will not lead, such as in the regulation of emissions across national or international jurisdictions. Whatever the future of coordination, it must not compromise the leadership of cities. This point highlights other important political and associated institutional lessons.

Cities do not need other levels of government to tell them how to mitigate climate change. Through changes to their own operations, Canadian cities show that they can independently take action that has meaningful impacts. Hence, globally, cities need not be encumbered by the inaction of other levels of government. Climate action produces co-benefits to cities, such as improvements in air quality and reductions in energy costs. These potential co-benefits, however, will likely be realized through knowledge sharing, capacity building, and technology transfers.

Municipal networks play an important role in facilitating knowledge transfer. But in the absence of the financial and technological resources to execute programs, the power of knowledge can be limited. The approach to project financing employed by international organizations like the Global Environment Facility (GEF) may be a useful model for city climate-related actions. GEF funds the 'incremental' or additional costs associated with transforming a project with national benefits into one with global environmental benefits. In turn, the GEF, or a new facility that specifically funds the incremental costs of transforming city infrastructure investments or improvements into ones that also reduce GHG emissions is appealing because of the potential to produce global benefits at the same time as direct benefits to cities and citizens. The Clinton Climate Initiative's approach to reducing the costs of energy-efficient infrastructure and technology is also an important model. By negotiating with manufacturers to reduce costs for energy-efficient technology, the initiative pools the purchasing power of cities. This model is important to consider at a national or regional scale as well.

The creation of a Clinton Climate Initiative-like entity in countries or regions seems to have significant merit for producing co-benefits to cities, their citizens, and the global climate. The Federation of Canadian Municipalities' (FCM) Green Municipal Fund (GMF) is a national example of such an entity. The Fund provides grants and below-market loans to municipalities to undertake environmental initiatives and GHG reductions. Since its inception in 2000, the GMF has committed more than $375 million in financing to support almost 700 sustainable community development projects, including sustainable community plans and feasibility studies, as well as loans and grants for capital projects (FCM 2008). Cities should not carry the burden of responding to climate change when national governments cannot. Therefore, any future technology transfer or infrastructure or climate-related urban financing must produce specific and real co-benefits to city governments and citizens. Cities in Canada show that achieving co-benefits through institutional programs are real, significant, and achievable.

In addition to urban leadership, cities in Canada show that achievements in climate action take time. Toronto is recognized as an international leader in climate action but it began its actions in 1988. Its achievements, like other cities, are the result of careful, prolonged action and political commitment. Recent research on US metropolitan areas also suggests that cities that have high levels of civic and environmental capacity are more likely to engage in GHG emission reduction efforts (Zharan et al. 2008). Despite this, after ten to twenty years of climate leadership, many Canadian cities are only now establishing concerted and specific efforts to engage citizens in climate campaigns. Hence, while the presence of strong state-society relations in cities may correlate with environmental action, it is not a precondition for climate action.

The climate-related initiatives and outputs of Canadian cities, particularly at the institutional level, are fairly consistent. These independent actions, along with the networks and programs many Canadian cities participate in, provide examples that other cities may carefully consider. It is unclear whether Canada's national government will build on the climate leadership of its cities in the near future. But in the absence of stronger collaboration with the national government and provinces, Canadian cities will continue to lead because the benefits of action are locally tangible, and globally meaningful — an outcome that should resonate with other cities around the world.

References

Bailey, J. 2007. *Lessons from the Pioneers: Tackling Global Warming at the Local Level.* Washington, DC: Institute for Local Self-Reliance.

Bradford, N. 2007a. "Whither the Federal Urban Agenda? A New Deal in Transition." Research Report F65, February. Prepared for the Canadian Policy Research Network (CPRN).

______. 2007b. "Placing Social Policy? Reflections on Canada's New Deal for Cities and Communities." *Canadian Journal of Urban Research* 16 (2): 1–26.

Bulkeley, H. 2005. "Reconfiguring Environmental Governance: Towards a Politics of Scales and Networks." *Political Geography* 24: 875–902.

Bulkeley, H., and Betsill M.M. 2003. *Cities and Climate Change: Urban Sustainability and Global Environmental Governance.* London: Routledge.

Climate Group. 2005. *Low Carbon Leader: Canada 2005*. http://theclimategroup.org/assets/resources/low_carbon_leader_canada.pdf. [last accessed, May 19 2008].

Environment Canada. 2006a. *Information on Greenhouse Gas Sources and Sinks. Canada's 2006 Greenhouse Gas Inventory - A Summary of Trends*. Ottawa: Government of Canada. http://www.ec.gc.ca/pdb/ghg/inventory_report/2006/som-sum_eng.pdf. [Last accessed on January 12, 2009].

______. 2006b. *Canada's Fourth National Report on Climate Change.* Ottawa: Government of Canada. http://www.ec.gc.ca/climate/4th_Report_on_CC_e.pdf. [Last accessed on January 12, 2009].

______. 2006c. *National Inventory Report. Greenhouse Gas Sources and Sinks in Canada, 1990-2006.* Ottawa: Government of Canada. http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/tdm-toc_eng.cfm. [Last accessed on January 12, 2009].

Environment Canada. 1999. *Six Successful Landfill Gas Utilization Projects Demonstrate Early Actions to Reduce Greenhouse Gases*. Ottawa: Environment Canada.

Federation of Canadian Municipalities. 2008. *Green Municipal Fund Annual Report 2007-2008*. Ottawa: FCM http://www.sustainablecommunities.fcm.ca/files/About_us/Annual_Reports/2007-2008-GMF-AR-e.pdf. [Last accessed on April 20, 2009].

Federation of Canadian Municipalities. 2009. *Act Locally. The Municipal Role in Fighting Climate Change*. Report prepared for FCM by EnvironEconomics. http://www.fcm.ca//CMFiles/FCM_Climate_En_Final1RSG-1272009-2598.pdf. [Last accessed on March 13, 2010].

Gore, C. 2010. "The Limits and Opportunities of Network Analysis: Municipalities and Canadian Climate Policy." *Review of Policy Research* 27 (1): 27–46.

Gore, C. and Robinson, P. 2009. "Local Government Response to Climate Change: Our Last, Best Hope?" In *Changing Climates in North American Politics*, ed. Henrik, Selin and Stacy VanDeveer. Cambridge, MA: MIT Press.

Hueglin, T.O. 2007. "The Principle of Subsidiarity: Tradition-Practice-Relevance." In *Constructing Tomorrow's Federalism. New Perspectives on Canadian Governance*, ed. Ian Peach. Winnipeg, Manitoba: University of Manitoba Press.

MacDonald, D., and Smith, H. 1999. "Promises Made, Promises Broken: Questioning Canada's Commitment to Climate Change." *International Journal* 5 (1): 107–24.

MacDonald, D. 2008. "The Failure of Canadian Climate Change Policy: Veto Power, Absent Leadership, and Institutional Weakness." In *Turning Down the Heat: The Politics of Climate Policy in Affluent Democracies,* ed. H. Compston & I. Bailey. New York: Palgrave.

Municipalities Issue Table. 1999. *Options Paper*. Ottawa: Government of Canada, National Climate Change Program.

Pralle, S. 2006. "The "Mouse that Roared": Agenda Setting in Canadian Pesticides Politics." *Policy Studies Journal 34* (2): 171–94.

Pembina Institute. 2009. "McAllister Opinion Research Poll on Canadians' Opinions on Global Warming." http://pubs.pembina.org/reports/bg-polling-results-final.pdf. [Last accessed on April 19, 2009].

Rabe, B.G. 2007. "Beyond Kyoto: Climate Change Policy in Multilevel Governance Systems." *Governance*, 20 (3): 423–44.

Robinson, P. 2009. "Beyond a Technical Response: New Growth-Management Experiments in Canada." In *Planning for Climate Change: Strategies for Mitigation and Adaptation for Spatial Planners,* ed. Simin Davoudi, Jenny Crawford and Abid Mehmood. London: Earthscan Publications.

______. 2006. "Canadian Municipal Response to Climate Change: Measurable Progress and Persistent Challenges for Planners." *Planning Theory and Practice, Interface* 7 (2): 218–23.

Robinson, P., and Gore C.D. 2005. "Barriers to Canadian Municipal Response to Climate Change." *Canadian Journal of Urban Research* 14 (1): 102–20.

Sancton, A. 2006. "Cities and Climate Change: Policy-Takers not Policy-Makers." *Policy Options* 27 (8): 32–34.

Slack, E., and Bird R.M. 2007. "Cities in Canadian Federalism." *Policy Options* (December-January): 72–7.

Stevenson, D., and Gilbert R. 2005. "Coping with Canadian Federalism: The Case of the Federation of Canadian Municipalities" *Canadian Public Administration* 48 (4): 528–51.

Zahran, S., Grover H., Brody S.D., and Vedlitz A. 2008. "Risk, Stress and Capacity: Explaining Metropolitan Commitment to Climate Protection." *Urban Affairs Review* 43 (4): 447–74.

CHAPTER 20

Climate Change Adaptation Planning in Toronto: Progress and Challenges

Jennifer Penney,* Thea Dickinson, and Eva Ligeti

Summary

The City of Toronto is one of the first Canadian cities to establish a citywide process to respond to its vulnerability to climate change. In 2008, Toronto developed Ahead of the Storm, a climate change adaptation strategy. This case study describes past, current and potential future impacts of climate change on Toronto, along with the steps taken to develop the adaptation strategy. These steps include the creation of an Adaptation Steering Group and the development of an initial framework document. The strategy was underpinned by existing programs that provide protection from current weather extremes and included short term actions as well as a longer-term process for developing a comprehensive strategy. The City is in the early stages of implementing the strategy. This paper also reflects on some of the barriers to the integration and mainstreaming of adaptation into City plans and programs.

*Corresponding author: cap@cleanairpartnership.org

1. INTRODUCTION

In the last decade, public awareness of climate change has increased dramatically in Canada, and changing weather trends, extreme weather events, and associated impacts are being blamed – rightly or wrongly – on climate change. Municipalities are responsible for many affected services and infrastructure: electricity distribution; water supply; stormwater management; the state of local roads, bridges, and culverts; public health; social welfare; and more. As a consequence, a growing number of local governments are considering how to respond to climate change.

Toronto is Canada's largest city and has often been a leader in the development and implementation of many new environmental policies. In 2008, after almost a year of planning, the City adopted a new Climate Change Adaptation Strategy (City of Toronto 2008a) and is now in the early stages of implementing it. Although Toronto is not the first municipality in Canada to undertake explicit adaptation planning — Halifax has that distinction — lessons learned from Toronto's experience are likely to influence the development and implementation of adaptation programs elsewhere in the country.

2. CONTEXT

2.1. The City of Toronto

Toronto is situated on the northwestern shore of Lake Ontario, the smallest of North America's Great Lakes.

It is the capital of the province of Ontario and Canada's largest city, with approximately 2.7 million inhabitants in an urban region of more than 5 million people. Toronto is one of the most multi-cultural cities in the world. According to the 2006 Census, 49.9% of Toronto's population is foreign-born. Children (0-19 years) made up almost 24% of the city's population in 2009 while 12% of the population is over the age of 65 (Toronto Region Research Alliance 2010). Despite the influx of new immigrants, Toronto's population is gradually aging.

Toronto has a humid continental climate moderated by its location on Lake Ontario. The city experiences warm, humid summers and cold winters with some snow and periods of freezing rain.

2.2. Emerging Climate Change Impacts and Concerns

Until recently, the City of Toronto paid greater attention to reducing greenhouse gas emissions than to local climate change impacts and the need for adaptation. This has begun to change as Toronto's weather has become noticeably more extreme. In the last four years, Toronto has suffered through the hottest and smoggiest summer in the City's history (2005), the most intense rainfall and costliest flood (also 2005), one of the driest summers on record (2007) followed by the wettest summer (2008), and the snowiest winter in 70 years (2007-2008).

These weather events drew the City's attention to the following expected climate change impacts:

2.2.1 Heat Waves and Declining Air Quality

Toronto's summer temperatures have climbed an average of 2.7ºC in the last forty years, due to a combination of climate change, the urban heat island effect and the increase in Lake Ontario's surface temperature caused by the use of the Great Lakes as heat sinks by nuclear and coal-fired power plants (Rhodes 2008). The incidence and duration of heat waves has also increased. In response to this, Toronto Public Health (TPH) launched a heat alert and response system in 1999. TPH also commissioned a study which evaluated mortality due to heat waves (Pengelly et al. 2005). The study estimated that heat waves currently contribute to an average of 120 deaths annually in Toronto. However, as a result of climate change, heat-related mortality is projected to double by 2020 and triple by 2080, in the absence of effective adaptation (Pengelly et al. 2005). Hotter weather and prolonged heat waves also negatively affect air quality. Pengelly et al. estimated that 1,700 people die prematurely in Toronto and about 6,000 are hospitalized each year from exposure to smog and other air pollutants. The study predicted that these figures would rise 20% by 2020 and 25% by 2080 as a result of climate change.

Rising summer temperatures also have a significant impact on Toronto's electricity demand, which soars on hot days and triggers the purchase of electricity from coal-fired generating stations in the Ohio Valley. This increases greenhouse gas emissions, and intensifies air pollution and smog in Southern Ontario, which is downwind of these plants. The increase in demand also strains the electrical transmission systems, increasing the risk of brownouts and blackouts.

2.2.2 Intense Rainfall and Flooding

For some time Toronto Water has been concerned about the escalating intensity of rainstorms, which caused eight local floods between 1986 and 2006 (D'Andrea 2007). A three-hour storm on August 19, 2005 dropped more than 150 mm of rain on some areas of the city and cost at least half a billion dollars in flood damages — the most expensive natural disaster ever in Ontario (Yakabuski 2008). Impacts included: flash floods of creeks, rivers and ravines; the erosion and collapse of stream banks; more than 4,200 flooded basements in homes and commercial properties; and damage to parks, trees, roads, water mains, gas mains, underground electrical and telephone cables, sanitary sewers and bridge foundations, as well as vehicles (D'Andrea 2007).

2.2.3 Record Snowfalls and Freezing Rain

Although changes in snowfall trends in Southern Ontario are not considered statistically significant up to the year 2000 (Zhang et al. 2001), a number of extreme snowfall events have occurred in Toronto since the late-1990's. For example, 118 cm of snow fell in a two-week period in January 1999, more than usually falls in an entire winter. Toronto's former Mayor requested help from the military to clear away one million tons of snow from the downtown area. Snow clearing that month cost $70 million, more than twice the City's budget for the entire year (Environment Canada 2006). Major snowstorms were also experienced in 2001, 2002 and 2005. In the winter of 2007-8 snowfall totaled 194 cm, the most snow the city had seen in 70 years. This resulted in multiple power outages, traffic pile-ups and airport closures, and snow-clearing costs again greatly exceeded the budget for the year. The City attributes record snowfalls to later freeze-up of the Great Lakes, resulting in more moisture in the air when winter storms arrive (City of Toronto Transportation Services 2009). Also of concern are freeze-thaw cycles, which damage roads as well as trees and plants, and increases in freezing rain, which result in traffic accidents and deaths.

2.2.4 Impacts on the Urban Forest

Toronto's trees make the city more beautiful and more livable. In 2007, the City of Toronto committed to doubling its tree canopy from 17 to 34% coverage by 2050 to cool the city, reduce stormwater runoff, absorb some air pollutants and sequester carbon (City of Toronto 2007a). Climate change will challenge the City's ability to meet this goal. Toronto's canopy has actually declined 4 – 5 % in the last 15 years. Increases in heat, erratic precipitation, storms, and exotic pests — all exacerbated by climate change – make life difficult for urban trees (Johnston 2004; Wieditz and Penney 2007).

3 TAKING ACTION ON ADAPTATION

3.1. Including Adaptation in Toronto's Climate Change Plan

Despite growing awareness of climate change impacts, when a new City Council decided in late 2006 to create an ambitious new climate change plan, adaptation was not yet top of mind. Adaptation was included in the plan at the urging of the Clean Air Partnership (CAP), a local non-governmental organization. CAP had published *A Scan of Climate Change Impacts on Toronto* (Wieditz and Penney) in 2006, and met individually with the Mayor and many City Councillors to discuss the need to adapt to avoid the worst impacts. CAP also hosted two workshops for

City of Toronto staff on the issue. Two key City Councillors — the Chair and Vice Chair of the City's Parks and Environment Committee — became convinced that adaptation was necessary. As a consequence, the City incorporated a commitment to investigate Toronto's vulnerability to climate change in *Change is in the Air*, the City's climate change plan, adopted in the summer of 2007 (City of Toronto 2007b).

3.2 The Adaptation Team

To guide this work, the Toronto Environment Office (TEO) established an Adaptation Steering Group. The group consisted of policy and program staff from 14 City Divisions and Agencies expected to be impacted by climate change. TEO also set up and chaired a core group of seven staff to undertake the day-to-day work of mapping out an adaptation plan and managing the public consultation process. This group met almost weekly from September 2007 until April 2008.

Six departments — Toronto Public Health, City Planning, Toronto Water, Transportation Services, Urban Forestry and Financial Services — expressed great interest in a citywide adaptation project, as did the Toronto and Region Conservation Authority, which had been working hard for several years on the issue. However, there were pockets of resistance in some areas. A few staff expressed skepticism about climate change. Others felt that uncertainties in the science — especially about the frequency and intensity of storms and changes in precipitation patterns — precluded taking action at this time. Some staff members were concerned about additional workload, and others felt that new adaptation measures would likely prove too costly in light of the financial pressures on the City. The Deputy City Manager advised staff, however, that the adaptation project required their cooperation.

Over eight months, the Adaptation Steering Group completed a framework document that outlined the issues, developed a broad adaptation strategy, and ushered it through a public consultation process.

3.3 Building Capacity and Engagement

Many members of the Adaptation Steering Group had little previous experience in assessing climate change impacts or planning to adapt and they faced a steep learning curve. The Chair of the group undertook a number of activities to provide information on impacts and adaptation to group members and in some cases to engage other key City staff. These activities included:

- Compiling information about what other municipalities were doing on the issue;
- Encouraging attendance at workshops and conferences to increase familiarity with concepts and issues in climate change impacts and adaptation;

- Participating in the regular webinars of the new Alliance for Resilient Cities as well as meetings of its U.S. counterpart, the Urban Leaders Adaptation Initiative; and
- Organizing meetings with the Climate Change Scenarios Network, the Public Infrastructure Engineering Vulnerability Committee, the Canadian Institute of Planners, and others to help the City with thinking about climate change scenario modeling, infrastructure risk assessment and other adaptation-related issues.

To increase internal engagement, the Chair of the Adaptation Steering Group arranged individual meetings with key divisions, including: Insurance and Risk Management, Community Development, Water Infrastructure Management, the City's Emergency Management Working Group, the Economic Development Office, Toronto Public Health, Toronto Hydro and the Executive Environment Team. These meetings included presentations about climate change and its potential impacts in the region and engaged officials in discussions about what they might need to do to respond. TEO also met with the Mayor and with the Chair of the Parks and Environment Committee to brief them on the developing adaptation strategy and public consultation process.

The Adaptation Steering Group invited a number of climate and adaptation scientists, analysts from the insurance industry and infrastructure engineers to join an Expert Panel to provide advice. Members of the Expert Panel made presentations at two key meetings: an internal meeting with senior staff from the City's Divisions held in November 2007, and a large public meeting of the City's Parks and Environment Committee in January 2008, attended by more than 100 members of City staff, local environmental organizations, the public and the press. The Expert Panel presentations gave City staff and political officials a sobering preview of potential climate impacts on the City, including the costs of not taking action to prepare for expected changes.

3.4 Developing a Framework Document

The Adaptation Steering Group developed a "framework document" to help inform internal and public discussion about climate change impacts and adaptation. This document proved harder to compile than expected. The issues were new for many of the members, and the group was attempting to devise, without a good precedent, a comprehensive strategy for a large and complex city. Several international cities had begun adaptation planning, but few had made detailed information available about their processes, so there were few examples to follow (Penney and Wieditz 2007). When the first draft was completed, fourteen City departments made detailed — and in some cases divergent — recommendations, which had to be considered in reworking the document.

The final framework document was called *Ahead of the Storm: Preparing Toronto for Climate Change* (City of Toronto 2008b). It provided information on the impacts Toronto can expect from climate change, explained why adaptation is necessary and recommended a long-term process for developing a comprehensive adaptation strategy for Toronto. This longer-term process has nine steps:

- Create the internal mechanisms and processes for the development of a comprehensive, multi-year adaptation process;
- Engage the public, business and other stakeholder groups;
- Incorporate climate change adaptation into City policies and high level plans;
- Use best available science to analyze how climate is changing locally and what the future is likely to bring;
- Use this analysis to identify Toronto's vulnerabilities to climate change;
- Conduct a risk assessment to identify priority impacts requiring adaptation action;
- Identify and assess adaptation options to reduce the risk;
- Develop and implement climate change adaptation strategies; and
- Monitor climate change, evaluate the effectiveness of adaptation initiatives in protecting the City from continuing changes, and adjust strategies when necessary.

Ahead of the Storm identified a number of existing programs that serve to provide protection from current weather extremes, and which provide a basis for building a more comprehensive adaptation program aimed at protecting against future impacts of climate change. The framework document also proposed a number of short-term projects that could be undertaken immediately, and could help address current and future impacts. Some of these projects are included in Table 1.

The Toronto Environment Office produced a shorter "highlights" version of the framework document to help in the public consultation process. This report was distributed in print form and made available on the City of Toronto website.

TABLE 1
A Selection of Short-term Adaptation Projects Recommended in the Toronto Strategy

Recommended Short-term Adaptation Projects	Anticipated Benefits
Study of Recent Regional Climate Trends and Future Climate Projections	Improved information on expected climate extremes as well as likely gradual changes to permit better decision making on adaptation planning and for use in next generation watershed plans.
Climate Change Vulnerability and Risk Assessment of City Operations	Improved understanding of where vulnerabilities are and ranking of risks to help prioritize adaptation actions
Updating of regional extreme precipitation intensity, duration and frequency curves	Improved ability to design storm drainage infrastructure for extreme runoff events
Scan of methods used in other jurisdictions for assessing vulnerability to heat	Leading to development of heat-related vulnerability assessment tool to provide strategic direction for Toronto's Hot Weather Response Plan
Analysis of when and where green roofs could be required	Support for a new Green Roof by-law expected to reduce demand for air conditioning and storm water runoff
Urban Heat Island research to inform land use planning policy approaches to "cooling" the City	Identification of Toronto's "hotspots", what causes them, and strategies to reduce them
Climate change vulnerability risk assessment of major road culverts and bridges	Informing upgrades to infrastructure, and reducing the risk of infrastructure failure due to extreme weather, so that disruptions to the public and significant insurance claims can be minimized
Expand parkland naturalization and naturalization of lands surrounding water and wastewater facilities	Increased canopy cover in our parks and open spaces from 30% to over 50% and reduced stormwater runoff
Introduce a new standard for supporting healthy tree growth by continuous soil trench systems in commercial areas	Extended life of trees from 6 years to 35 years in commercial areas, increasing shade, and reducing energy demand for cooling
Elimination of new reverse slope driveways	Reduced flooding during extreme precipitation events

Source: Adapted from Ahead of the Storm (City of Toronto 2008b)

3.5 Consulting the Public and Other Stakeholders

The Toronto Environment Office held six meetings to consult the public and stakeholders on *Ahead of the Storm*. Each of the meetings began with a presentation of the main issues and recommendations from the document. Attendees were then invited to discuss the impacts they felt were key, any gaps they saw in the City's analysis and action the City should take.

Many of the participants at the consultation meetings struggled with the concept of climate change adaptation. They were much more familiar with – and many were more committed to — mitigation measures to reduce greenhouse gas emissions than adaptation. Business representatives were quick to understand some of the potential impacts of climate change, since several had experienced the adverse economic effects of power outages, floods and other results of extreme weather (David MacLeod, personal communication, May 26, 2008). As a result, business groups had a strong focus on emergency response issues. All the meetings recommended that the City should increase and broaden education programs to make Torontonians aware of the threats of climate change and potential adaptation solutions.

3.6 Political Commitments and Early Implementation

Following the public consultations, the Toronto Environment Office prepared a Staff Report on a *Climate Change Adaptation Strategy* with recommendations for Council (City of Toronto 2008a). The report was adopted unanimously by Council on July 15, 2008. The main commitments of the report and the implementation to date are as follows:

3.6.1 Incorporate Explicit Goals for Adaptation of Infrastructure and Buildings into Toronto's Official Plan

Toronto's Official Plan comes up for review in 2010. As instructed by Council, City Planning is currently developing specific commitments for climate change mitigation and adaptation to include in the Official Plan (Lisa King, personal communication, April 4, 2009). Because the Official Plan guides all land-use planning and development for the City, this will ensure that climate change impacts are taken into account in all new developments and major redevelopments.

3.6.2 Incorporate Climate Change Adaptation Initiatives into Planning and Budgeting of all City Agencies and Divisions for 2009

In the fall of 2008, Toronto's Deputy City Manager required all City Divisions to incorporate climate change mitigation and adaptation into their programs and to identify climate change activities in their budget submissions for 2009. This directive was announced just a few months before the new budgets were due;

as a result, few brand new climate change adaptation initiatives were included in Divisional plans. However, adaptation was highlighted in Division plans and budget submissions in a way that had not occurred previously, and several existing programs were strengthened or expanded in order to better address current climate extremes and future climate change. For example:

- The *Parks, Forestry and Recreation Division* successfully appealed for extra funds to expand the maintenance of existing trees, increase tree planting and support research into effective ways of improving the health and growth of urban trees and increasing the tree canopy (City of Toronto Parks, Forestry and Recreation 2009). These activities are aimed at achieving the City's goal of doubling the tree canopy in the next 40 years, and reducing the urban heat island effect and stormwater runoff among other benefits. Urban Forestry has also altered and diversified tree species being planted to better withstand the expanded range of pests and more extreme conditions expected under climate change.

- For several years, *Toronto Water* has incorporated concerns about climate change into its planning and programs. Recently, the Division identified 31 areas within the City prone to flooding and sewage backup as a result of more extreme rainfall and is undertaking a detailed analysis for each area to identify ways to reduce the risk of future flooding. Toronto Water expects to allocate several hundred million in capital projects over the next ten years to address this issue (Toronto Water 2008). The Division is also implementing a Water Efficiency Plan that is expected to reduce pressures on the water supply system in cases of drought. Toronto Water is also collaborating with the Toronto Region Conservation Authority and adjacent municipalities to update standards for stormwater infrastructure to better protect against intense rainfall.

- *Toronto Public Health* is conducting research in order to identify and map Toronto populations vulnerable to heat, with a view to developing a more targeted heat response system that may be more effective in protecting citizens during hot days and heat waves. With the support of the Medical Officer of Health, the Environmental Protection Office at Toronto Public Health is also trying to insert climate change concerns into a broader strategic review of priorities (Stephanie Gower, personal communication, April 4, 2009).

- In 2006, City Council adopted a Green Development Standard prepared by *City Planning*. It set demanding environmental standards for new City-owned buildings and encouraged developers to apply the standards to private developments as well (City of Toronto 2007b). Several requirements of the Standard serve to reduce Toronto's vulnerability to climate change by: mitigating the urban heat island effect; enlarging the urban forest; increasing shade for pedestrians; using permeable surfaces to reduce flooding, promoting on-site water storage and reuse; and encouraging drought resistant plantings. Planning officials are also piloting community-scale renewable energy generation and local distribution systems designed to enhance neighborhood energy security. This year the City revised the standard and as of September 2009, its minimum requirements (Tier 1) apply to all new developments in the City. The City will offer incentives to developers to achieve a higher standard (Tier 2) as well. City Planning is also working with Toronto Building on a by-law that will require green roofs on new buildings and establish construction standards for them.

- The new Eco-Roof Program, managed by the *Toronto Environment Office*, was launched March 2009 and provides a financial incentive for existing commercial, industrial and institutional buildings to install green roofs or cool roofs on their buildings. This expands on the previous Green Roof Pilot Program run by Toronto Water in 2006-7. Green roofs absorb rainfall and slow the flow of stormwater, potentially reducing urban flooding from intense storms. They also insulate the buildings below them, cooling them naturally, reducing the need for air conditioning in hot summers, and reducing peak demand for electricity and pressure on the grid during hot days and heat waves. "Cool roofs" reflect solar radiation, reduce heat in buildings, and lower demand for electricity as well.

Although these initiatives are all encouraging indicators of the integration of adaptation into City programs, some of the short-term adaptation projects proposed for specific Divisions in *Ahead of the Storm* were not included in 2009 budget proposals and some Divisions did not include any adaptation initiatives in their proposals. None of the new or expanded programs have utilized future climate projections to establish specific adaptation targets, though this may change when the Toronto Environment Office has concluded its study of recent climate trends and future climate projections for the region. (See section 3.6.4 below.)

3.6.3 To Investigate a Funding Strategy for Climate Change Adaptation Planning and Actions, Including the Creation of an Extreme Weather Reserve Fund

In January 2009, the City created an Environmental Protection Reserve Fund. Among other goals, the Fund is expected to support the development of Toronto's long-term adaptation strategy and for related projects such as Deep Lake Water cooling and expanding the tree canopy. The City committed $500,000 from this fund for the climate and risk assessment studies described in the next section.

At the recommendation of the City's Financial Services Division, Council also created the Extreme Weather Reserve Group of accounts to offset budget deficits arising from unexpected and unbudgeted extreme weather costs to City programs and services (City of Toronto 2009a). Such a fund could help pay the costs of extreme weather events like the 2005 flood or the unprecedented snowfalls of 2007-8 without diverting finances from other City priorities. Unfortunately, Council decided that the funds for the Extreme Weather Reserve Group are to be provided out of end-of-year surpluses. Given the current economic climate, such surpluses seem unlikely in the near future, which leaves City operating budgets vulnerable to extreme weather events.

3.6.4 To Establish a Process for the Development of a Longer-Term, Comprehensive Adaptation Strategy

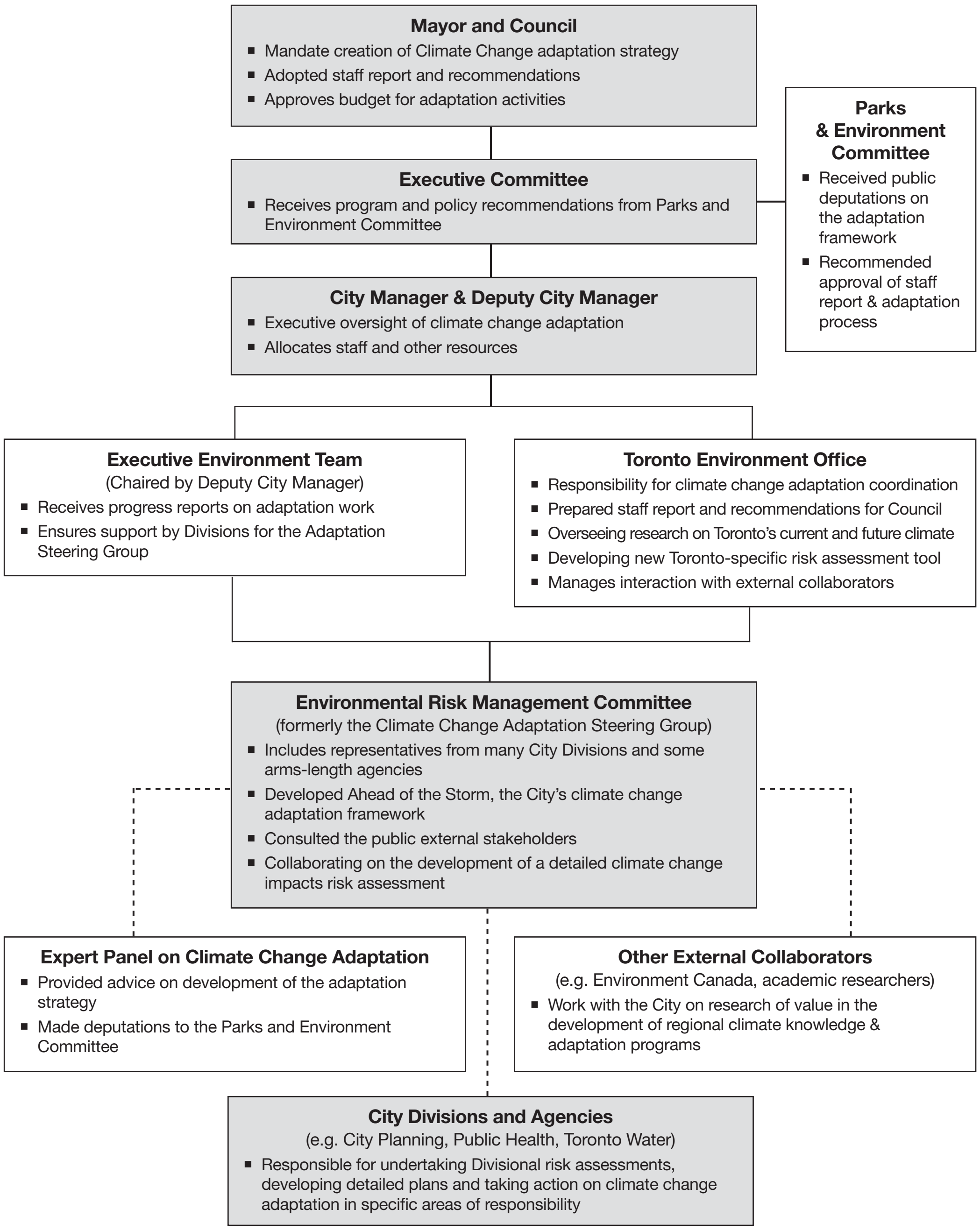
The City has two current projects to support development of a longer-term adaptation strategy. The Toronto Environment Office is working with a consultant, as well as with Environment Canada, the Ontario Ministry of the Environment and the Toronto Region Conservation Authority, to analyze Toronto's current and expected future weather patterns. Particular attention will be paid to the magnitude, frequency and probability of extreme events and the main drivers that contribute to them. The study will identify the tools and data that can be used to predict future weather and climate for the region, which should be useful in planning, especially for long-lived infrastructure (City of Toronto 2009b). Expected to be released in 2010, the study should be of value for the whole of southern Ontario (Christopher Morgan, personal communication, April 4, 2009).

The Toronto Environment Office has also hired a consultant to develop a risk assessment methodology for identifying and prioritizing environmental risks that the City faces. This tool is being piloted by two Divisions within the City — Transportation Services and Shelter, Housing and Support — to assess the risks that climate change poses for the operations of these Divisions. This task is still underway at the time of writing. If the pilot is successful, the City's other Divisions and Agencies are expected to use the methodology to undertake detailed climate change risk assessments, which should inform the development of a more detailed adaptation strategy.

3.6.5 To Help Establish and Develop an Urban Climate Change Network

The idea for a Toronto Urban Climate Change Network (TUCC Network) was proposed at the first consultation meeting on *Ahead of the Storm*, which brought together academics from three local universities, representatives from the environmental departments of the provincial and federal governments, and non-governmental organizations with knowledge of adaptation issues. Participants in this consultation supported the idea of an ongoing forum where they could promote collaboration and practical research that could help in the implementation of adaptation policies and programs in the Toronto region. With City Council's approval, TEO set up the TUCC Network in the fall of 2008.

FIGURE 1
Organization of Toronto's Adaptation Work



Note: This chart has been adapted from a diagram by David Macleod of the Toronto Environment Office, but has not been approved by the City. It is provided for illustrative purposes only.

One of the first activities of the Network was to organize the *Forum on Infrastructure and Climate Change Adaptation* (Forum) in April 2009, designed to promote the integration of climate change considerations into urban infrastructure projects that are currently on the upswing because of new economic stimulus investments. A large number of City staff attended this Forum and participated actively in its discussions, which focused on potential climate change impacts for five broad areas of infrastructure:

- Transportation;
- Drainage and water;
- Buildings;
- Natural spaces; and
- Energy.

For each area, roundtable groups at the Forum identified critical vulnerabilities, key data needs and priority areas for action. Additionally, the Forum strongly recommended the creation of a Toronto Climate Change Adaptation Working Group of decision-makers to encourage the uptake of adaptation actions in the private and public sectors and in the community. The City agreed to convene this group, but as of April 2010, this has not been done.

4. DISCUSSION

Toronto is one of a handful of North American cities (Chicago, New York, Los Angeles) that has made a commitment to comprehensive climate change adaptation. It is still too early in the process to provide a full assessment, but the overall outlook is quite positive.

The work of the last three years has led to a substantial increase in the awareness and engagement of City politicians and staff on this issue. Staff members —including senior staff — from most of the City's Divisions have attended a variety of presentations and workshops on climate impacts and adaptation and participated in discussions on ways to move the agenda forward. There is an increased understanding that a number of existing programs that protect against the effects of existing climate variability can also provide a strong basis for future adaptation efforts.

In addition to these internal activities to increase awareness and engagement, the City has reached out to community members and to other organizations that have an interest in adapting to climate change by means of public and business consultations on *Ahead of the Storm* and by establishing the Toronto Urban Climate Change Network. The proposed Adaptation Working Group, expected to include both public and private decision-makers, would expand this outreach further. The City is also heavily involved with a new Ontario Regional Adaptation Collaborative, which should raise the profile of climate change adaptation throughout the province, and stimulate an even wider range of discussion and activity.

Adaptation is beginning to be explicitly incorporated into City-wide plans and high-level policies, starting with Toronto's Official Plan. The requirement for Divisions to specifically address mitigation and adaptation in their budget submissions is also a major step forward in mainstreaming adaptation thinking and action.

Several City Divisions have integrated climate change adaptation activities into their individual planning and programs, and embarked on short-term projects to assess potential climate impacts and the adequacy of current responses. Some are in the process of strengthening existing programs that provide protection from extreme weather.

This array of current projects and activities is not yet welded together into a detailed long-term strategy, however, and there are both internal and external barriers to the development and implementation of such a strategy.

First, it is hard to get decision-makers to commit to what could be expensive and far-reaching adaptation projects and retrofits where they are not convinced about the extent and the timeline of expected changes. There is still considerable uncertainty in climate change projections and in the identification of impacts for the region (Ontario Expert Panel on Climate Change Adaptation 2009). TEO has undertaken two research projects to tackle these issues, both of which will report by the end of 2010. A number of climate modeling projects that involve scientists from Environment Canada and universities in Southern Ontario are also likely to provide better regional projections in the near future. The Toronto Regional Conservation Authority is also working with Environment Canada, other Southern Ontario conservation authorities, and municipalities on a study to develop new Intensity, Duration and Frequency curves to better anticipate the frequency and intensity of future localized storms. All of these activities should reduce knowledge and uncertainty barriers.

While the City has dozens of staff working on projects and programs related to climate change mitigation, it has not made a similar commitment with respect to adaptation. Activity by the Adaptation Steering Group — with representatives from most City Divisions — diminished after City Council adopted the Climate Change Adaptation Strategy, at a time when the hard work of implementing an integrated strategy needed sustained attention. This group has now been reconstituted as an Environmental Risk Management committee with a broader mandate that includes adaptation. This could result in the mainstreaming of adaptation within City Divisions, but might also result in dilution of the adaptation effort. This remains to be seen.

Another issue is financial resources. The global economic recession hit the City hard. This resulted in Toronto's decision to base its new Extreme Weather Reserve

Fund on end-of-year surpluses — which look unlikely in the near future. Like other cities, Toronto has a major infrastructure deficit stemming from cutbacks in spending by governments at all levels during the previous two decades, The Federation of Canadian Municipalities estimates Canada's municipal infrastructure deficit at $123 billion (Mirza 2007). While the need to replace crumbling infrastructure may be regarded as an opportunity for incorporating adaptation into new transportation, water, stormwater and other systems, available financing to upgrade or replace existing systems is inadequate. Where new funding is available — such as that provided by the federal government's economic stimulus package — there is pressure to get projects built quickly, which is likely to reduce the integration of climate change adaptation measures in the projects.

Despite these challenges, it is important to recognize the leadership that Toronto has shown as one of the first urban centers in Canada to acknowledge the need for climate change adaptation and to take substantive action to tackle the problem. Toronto has made significant headway in the development and implementation of climate change adaptation plans and activities. It will be important for the City to maintain focus and momentum in order to weld together a coordinated and comprehensive strategy out of the array of activities on which it has embarked, to protect its citizens from the impacts of climate change.

References

City of Toronto. 2003. *Wet Weather Flow Master Plan.* City of Toronto, Toronto.

______. 2007a. *Change is in The Air: Climate Change, Clean Air and Sustainable Energy Action Plan.* City of Toronto, Toronto.

______. 2007b. *The Toronto Green Development Standard.* City of Toronto, Toronto.

______. 2008a. *Climate Change Adaptation Strategy. Climate Change Adaptation.* http://www.toronto.ca/legdocs/mmis/2008/pe/bgrd/backgroundfile-12950.pdf. [Accessed April 12, 2009].

______. 2008b. *Ahead of the Storm: Preparing Toronto for Climate Change.* City of Toronto, Toronto.

______. 2008c. *Ahead of the storm: Preparing Toronto for Climate Change – Highlights.* City of Toronto, Toronto.

______. 2009a. *By-law No. 66-2009.* Executive Committee. http://www.toronto.ca/legdocs/mmis/2009/cc/bills/bill65.pdf. [Accessed April 5, 2009].

______. 2009b. *Request for Proposals: Toronto's Future Weather and Climate Driver Study.* City of Toronto, Toronto.

City of Toronto Parks, Forestry and Recreation. 2009. *Analyst Briefing Notes: Parks, Forestry and Recreation 2009 Operating Budget.* Budget 2009. http://www.toronto.ca/budget2009/pdf/op09_an_pfr.pdf. [Accessed April 4, 2009].

City of Toronto Transportation Services. 2009. *Analyst Briefing Notes: Transportation Services 2009 Operating Budget.* Budget 2009. http://www.toronto.ca/budget2009/pdf/op09_an_transportation.pdf. [Accessed April 4, 2009].

D'Andrea, M. 2007. "Climate change: Impacts on infrastructure and water management." Presentation to the Columbia Basin Trust Workshop: Changing Climate, Changing Basin, Cranbrook, British Columbia, November 28–29, 2007.

Environment Canada. 2006. *Historical Snow-related Events. Atmospheric Hazards.* http://ontario.hazards.ca/historical/Snow_Ontario-e.html. [Accessed April 12, 2009].

Johnston, M. 2004 "Impacts and adaptation for climate change in urban forests." Presentation to the 6th Canadian Urban Forest Conference, Kelowna, British Columbia, October 19–23, 2004.

Mehdi, B., ed. 2006. *Adapting to Climate Change: An introduction for Canadian municipalities.* Sudbury: Canadian Climate Impacts and Adaptation Network.

Miller, D. 2007. *Climate Change: Why Cities Matter*. Office of the Mayor. http://www.toronto.ca/mayor_miller/speeches/climate.htm. [Accessed February 21, 2007].

Mirza, S. 2007. *Danger Ahead: the Coming Collapse of Canada's Municipal Infrastructure.* Ottawa: Federation of Canadian Municipalities.

Ontario Expert Panel on Climate Change Adaptation. 2009. *Adapting to Climate Change in Ontario.* http://www.ene.gov.on.ca/publications/7300e.pdf. [Accessed April 19, 2009].

Penney, J. Wieditz, I. 2007. *Cities Preparing for Climate Change: A Study of Six Urban Regions*. Toronto: Clean Air Partnership.

Pengelly, D., Cheng C., Campbell M. 2005. *Influence of Weather and Air Pollution on Mortality in Toronto*. Toronto: Toronto Public Health.

Rhodes, C. 2008. *Climate Change Temperature Data*. *Local Warming, Temperature Data, Climate Change.* http://www.xylenepower.com/TemperatureData.htm. [Accessed April 3, 2009].

Toronto Region Research Alliance. 2010. *General Demographics Report: Toronto Region, Ontario, Canada.* http://www.trra.ca/en/reports/TORegionGenDemo.asp. [Accessed April 19, 2009].

Toronto Water. 2008. *Toronto Water Recommended 2009 Budget: Backgrounder*. Budget 2009. http://www.toronto.ca/budget2009/pdf/2009TWbudgetbackgrounder.pdf. [Accessed April 4, 2009].

Wieditz, I., Penney, J. 2006. *A Scan of Climate Change Impacts on Toronto*. Toronto: Clean Air Partnership.

Wieditz, I., Penney, J. 2007. *Climate Change Adaptation Options for Toronto's Urban Forest.* Toronto: Clean Air Partnership.

Yakabuski, M. 2008. "Adapting to Climate Change: The Insurance Industry's Role." Presentation to a Special Meeting of the City of Toronto's Parks and Environment Committee, Toronto, Ontario, January 22, 2008.

Zhang, X., Hogg, W., Mekis, E. 2001. "Spatial and Temporal Characteristics of Heavy Precipitation Events over Canada." *Journal of Climate* 14 (9): 1923–36.

CHAPTER 21

Climate Change and Urban Planning in Southeast Asia

Belinda Yuen,* Leon Kong

Summary

The challenge of climate change is real and urgent in Southeast Asia. Southeast Asia is one of the world's fastest growing regions. This paper presents a desk review of the state of climate change research and policy in Southeast Asia. It highlights the challenges, knowledge gaps as well as promising practices, with a specific focus on urban planning interventions to increase cities' resilience to climate change. The discussion reflects on how urban form and planning can support people's sustainable choices in terms of transportation, housing and leisure activities, and conveys the drivers and barriers to urban planning as a strategy of climate proofing. Issues that can be addressed through appropriate urban policy, planning, design and governance are highlighted.

*Corresponding author: belyuen8@gmail.com

1. INTRODUCTION

Southeast Asia is a sub-region of Asia. It is located south of China and east of India, extending more than 3,300 km from north to south and 5,600 km from east to west. Much of Southeast Asia is within the tropical climatic zone with temperatures above 25°C throughout the year. The region is strongly influenced by the Asian monsoons, which bring significant amount of rainfall to parts of Southeast Asia. There are 11 countries in Southeast Asia, of which 10 are members of the regional economic organization, the Association of Southeast Asian Nations (ASEAN).[1] Timor-Leste is expected to join ASEAN in the near future. Economic cooperation and socio-cultural exchange aside, ASEAN offers a regional framework to discuss major issues faced by Southeast Asia, including climate change.

As with the rest of Asia-Pacific, Southeast Asia has witnessed strong population, urban and economic growth in recent decades. Its population has more than trebled from 178 million in 1950 to 560 million in 2006. Accounting for 8.6 percent of the world's population, Southeast Asia has a land area (4.5 million square kilometers) that is 3.1 percent of world's land area. It has a combined gross domestic product (GDP) of US$1,100 billion and a total trade of about US$1,400 billion (2006). There are huge variations between countries, in terms of land and population size, economic performance, governance practices, cultural traditions, ethnic groups, religions and languages. Indonesia is the largest country, both in terms of land area (1.89 million square kilometers) and population (236 million). It ranks 5th in world population.

Southeast Asia also contains several post-conflict states (for example, Cambodia and Timor-Leste) and some of the world's poorest countries (for example. Myanmar and Lao PDR). Much of Southeast Asia is low-income despite economic growth in recent decades. Only two countries, Brunei Darussalam and Singapore, are high-income economies. A third (38.6 percent) of Southeast Asian population lives with less than US$2 a day while 7.4 percent lives with less than US $1 per day. The Gini coefficient, a common indicator of income inequality, has increased in some economies, for example, from 30.4 in 1992 to 34.6 in 2002 in Lao PDR, from 42.9 in 1994 to 46.1 in 2000 in the Philippines and from 35.7 in 1993 to 37.5 in 2002 in Vietnam. These socioeconomic circumstances often spill over to the environment and impact on the climate, for example, problems of fire (such as when the poor uses fire as part of their land management), haze and biodiversity damage from unsustainable resource use.

This paper presents the desktop review of the state of climate change research and policy in Southeast Asia. The next section (Section 2) will review the climate challenges of rapidly developing Southeast Asia. Section 3 will examine the state of climate change research and policy in Southeast Asia. It will identify the knowledge gaps as well as promising practices, with specific focus on urban planning interven-

[1]ASEAN was established on 8 August 1967 in Bangkok by the five original Member Countries, namely, Indonesia, Malaysia, Philippines, Singapore, and Thailand. Brunei Darussalam joined on 8 January 1984, Vietnam on 28 July 1995, Lao PDR and Myanmar on 23 July 1997, and Cambodia on 30 April 1999.

tions to increase the cities' resilience to climate change. Section 4 will seek to reflect on how urban form and planning can support people's sustainable choices in terms of transportation, housing and leisure activities, and convey the drivers and barriers to urban planning as a strategy of climate proofing. Issues that can be addressed through appropriate urban policy, planning, design and governance will also be highlighted.

2. SOUTHEAST ASIA AND ITS CLIMATE CHALLENGE

While Southeast Asia is one of the world's least urbanized regions, its urban population is growing at unprecedented rates, 1.75 times faster than the world's urban population (Table 1). Human settlements degand the pressure from human activities and economic growth have expanded with urbanization. On a local basis, these factors have the potential to increase the vulnerability of ecosystems and communities to climate change. In 2006, 38 percent of people in Southeast Asia lived in urban areas. By 2030, this proportion is projected to increase to 56.5 percent (United Nations, 2004). In some countries, for example, Brunei, Indonesia, Malaysia and the Philippines, the urban proportion may rise beyond 60 percent. Singapore is 100 percent urbanized. In the process, villages have become towns and in some cases, mega-cities,[2] expanding rapidly often without proper planning.

TABLE 1
Southeast Asia Urbanization

	Level of Urbanization					
	Estimates and Projections (%)				Rate of Change (%)	
	1990	2000	2010	2020	1990-2010	2010-2020
World	43.0	46.7	50.8	55.1	0.83	0.82
Brunei	65.8	71.1	75.7	79.3	0.70	0.48
Cambodia	12.6	16.9	22.8	29.6	2.96	2.61
Indonesia	30.6	42.0	53.7	62.6	2.81	1.53
Lao PDR	15.4	18.9	22.6	27.6	1.91	1.99
Malaysia	49.8	61.8	71.8	78.1	1.83	0.84
Myanmar	24.9	28.0	33.9	41.0	1.55	1.89
Philippines	48.8	58.5	66.4	72.3	1.54	0.85
Singapore	100.0	100.0	100.0	100.0	0.00	0.00
Thailand	29.4	31.1	34.0	38.9	0.72	1.36
Timor-Leste	20.8	24.5	28.7	34.0	1.60	1.71
Vietnam	20.3	24.3	28.8	34.7	1.77	1.84

Source: UN-HABITAT 2007a: 352.

[2]Jones (2002) has estimated that 11 percent of Southeast Asian population lives in mega-urban regions. The population of Greater Jakarta, Manila and Bangkok each exceeds 10 million and growing.

Rapid urbanization strains the municipality's capacity to meet infrastructure and other urban service demands. Some 28 percent (57 million) of the region's urban population is living in slums. In some large, primate cities such as Phnom Penh, Jakarta and Manila, it is not uncommon to find a quarter or more of the population living in informal settlements. In metro Manila, for instance, 61 percent of its people are squatters. These informal settlements are often located in unsafe areas, which generate further risks to life, health and property, leaving them vulnerable to climate change. The region faces a range of urban environmental challenges, from rapidly expanding but poorly planned cities to forest fires, polluted air and water, inadequate water supply, sanitation and energy, deficient drains and flooding fears.

Increasingly, as much as 80 percent of national gross domestic product is generated within urban areas, usually through industrialization and foreign direct investment. Southeast Asia, like the rest of developing Asia, until the recent global economic slowdown, has been rapidly expanding its economy, leading to tremendous environmental changes. The economic growth of Singapore — one of 4 Asian tigers — through industrialization and increases in foreign direct investment, is occurring in the 'second tier' countries of Thailand, Indonesia, Philippines, Malaysia, and more recently, Vietnam. In many cases, the industrialization-led economic growth based on the development approach of 'grow first, clean up later' has been synchronous with rapid urban population growth, land use change and major environmental problems, including pollution and contamination of inland and coastal waters, deforestation and overexploitation of water resources and biodiversity, eroding the region's environmental sustainability. The United Nations Environment Program (UNEP) has ranked Jakarta, Indonesia and Bangkok, Thailand, among the world's most polluted mega-cities.

Environmental degradation is a major challenge in the region. Institutional responsibilities for urban environmental management are often unclear and weak, especially over problems of cross-boundary pollution (UN-HABITAT, 2003; von Einsiedel, 2004). Besides weak governance, the other contributing factors include economic development and new lifestyle, which has seen an explosion in the demand for private cars and energy consumption. Rising energy demands are currently being met by the burning of fossil fuels that pollute and generate increasing volume of greenhouse gases (GHG) emission. Energy production and consumption in Southeast Asia remain largely 'business as usual', generating enormous quantities of wastes into the environment. In 2006, the greater proportion, 71.4 percent of electricity and 92.4 percent of heat production in Southeast Asia is from coal (Table 2). At the same time, many people (59.2 percent) in Southeast Asia still have no access to electricity, especially in the rural areas (International Energy Agency, 2002). Much of Cambodia, for example, has no electricity. Phnom Penh, the capital, uses about 85 percent of the country's electricity production, leaving the rest of the country with the remaining 15 percent. Blackouts are a regular feature in many of its towns.

TABLE 2
Electricity and Heat Production in Southeast Asia, 2006

Production from	Electricity (GWh)	Heat (TJ)
Coal	2,575,094	2,311,306
Oil	141,906	109,762
Gas	251,490	67,219
Biomass	5954	12,697
Waste	2638	0
Nuclear	94,713	0
Hydro*	515,702	
Geothermal	17,126	0
Solar PV	109	
Solar thermal	0	0
Wind	4147	0
Tide	0	0
Other sources	0	0
Total Production	3,608,878	2,500,984

Source: International Energy Agency Statistics, http://www.iea.org/Textbase/stats/electricitydata.asp.
Note: * Includes production from pumped storage plants.

Southeast Asia as a whole has a low per capita emission of carbon dioxide when compared with the developed world over the medium term. Its emission by 2030 is expected to be 4.2 tons per capita compared with 6.7 in China, 10.8 in Japan, 21.9 in Australia and 23.0 in the United States (APERC, 2006). The low per capita emission is consistent with its low per capita income level. However, the per capita emission on a regional basis masks national variation. Two of its 11 countries, namely, Indonesia (0.48 percent) and Thailand (0.24 percent) are among the world's top 10 countries of historical responsibility for global carbon dioxide emissions (1850-2000).[3] Their emissions are comparatively small against that of the United States (29.6 percent) and European Union (27.1 percent). In 2002, Singapore's per capita carbon dioxide emission was 12.2 tons and expected to reach 18.8 tons by 2030.

Energy production and consumption in Southeast Asia are projected to produce a fourfold increase in total carbon dioxide emissions from 2002 to 2030, assuming status quo in energy production and consumption pattern. The emission figure will be twice that of Japan, almost a third that of USA and a quarter that of China in 2030. Control of GHG emissions is crucial for Southeast Asia. Additionally, wet rice agriculture produces methane, which contributes to GHG emissions. Forest fires related to the 1997-98 El Nino event have released approximately 1.2 billion tons of carbon to the atmosphere (Van der Werf et al,

[3]Data obtained from the Climate Analysis Indicators Tool of the World Resources Institute. Available at: http://cait.wri.org/.

TABLE 3
Some Major Disasters, 1980-2000, in Selected Countries

	Cyclones			Droughts		
	Number of Events	Loss of Lives		Number of Events	Loss of Lives	
	Annual Average	Annual Average	Per Million	Annual Average	Annual Average	Per Million
Cambodia	—	—	—	—	—	—
Indonesia	—	—	—	0.29	60.29	0.34
Lao PDR	0.19	2.67	0.6	—	—	—
Malaysia	0.1	12.86	0.6	—	—	—
Myanmar	—	—	—	—	—	—
Philippines	5.57	863.19	14.35	0.24	0.38	0.01
Thailand	0.71	30.24	0.54	—	—	—
Vietnam	2.24	435.24	6.4	—	—	—

	Earthquakes[1]			Floods		
	Number of Events	Loss of Lives		Number of Events	Loss of Lives	
	Annual Average	Annual Average	Per Million	Annual Average	Annual Average	Per Million
Cambodia	—	—	—	0.29	48.52	4.08
Indonesia	1.62	193.24	1.04	2.48	120.29	0.67
Lao PDR	—	—	—	0.43	3.29	0.75
Malaysia	—	—	—	0.43	4.43	0.24
Myanmar	—	—	—	0.29	9.05	0.20
Philippines	0.57	120.57	2.03	1.76	75.71	1.22
Thailand	—	—	—	1.33	78.52	1.37
Vietnam	—	—	—	1.00	137.90	1.98

Source: UN-HABITAT (2007a): 369.
Notes: 1. Include events equal or greater than a magnitude of 5.5 on the Richter scale.
— denote no information.

2004). According to the United Nations Environment Program, these forest fires are among the most damaging in recorded history. The loss of natural forest and tropical forest dieback will vastly increase global carbon emissions. Typically, clearance of 1 hectare of tropical forest will release about 500 m3 of carbon into the atmosphere (Jones et al, 2003).

The region contains some of the world's major biodiversity such as the lowland rainforest of the Indo-Malayan archipelago. Forests are commonly converted to cropland, paddy and pasture to respond to growing population and urbanization needs or lost through illegal logging. Areas affected include Kalimantan and Sumatra of Indonesia, Sarawak and Sabah of Malaysia and the mountainous areas of Mekong region in Vietnam, Cambodia, Laos, Myanmar and Thailand. Indonesia, for example, has lost 60 percent of its total forest (64 million hectares) over a period of 50 years, from 1950 to 2000, and the loss is continuing at the rate of 2 million hectares per year. Biodiversity is under threat. Hundreds of mammal and bird species have been declared threatened (UNEP, 1999). Widespread bleaching of coral reefs has been reported in Indonesia, Thailand, Cambodia and Malaysia (Preston et al, 2006). Forest under legal protection is not safe; some 56 percent of protected lowland forest in Kalimantan, Indonesia, has been wiped out in recent years, from 1985 to 2001.

Without effective management, rapid urban growth is expected to exacerbate existing problems of poverty, slums, pollution, water, sanitation, etc. With few exceptions, most municipalities cannot cope with the challenges of rapid urbanization. All the countries in Southeast Asia, with the possible exception of Singapore, are developing countries with little capacity to manage urbanization and climate impacts. Many are struggling to cope with the current climate variability to which they are exposed, including cyclone, earthquake, tsunami, rainfall extremes, floods and droughts with severe damage and loss of life (Table 3). Take the Nargis cyclone (2 May 2008). Its winds exceeding 190 kilometers per hour swept through Myanmar's biggest city, Yangon, for more than ten hours, flattening homes, uprooting trees, destroying power lines and creating a disaster of a scale that the country has not dealt with before. In Indonesia, some 75 to 80 percent of all natural disasters during the period of 2003-06 were linked to climatic change (*The Brunei Times*, 2008). Elsewhere, heavy rainfall and typhoon in 2008 have led to flooding in many Southeast Asian countries, including the Philippines, Indonesia, Lao PDR and Vietnam.

If global climate modeling is correct, the region's annual temperature will increase in the order of 0.4-1.3°C by 2030 and 0.9-4.0°C by 2070 while winter rainfall is projected to decrease (less than 10 percent by 2030 and approximately 20-30 percent by 2070). The effect of a rise in global sea level on the region may be as much as 3-16 cm by 2030 and 7-50 cm by 2070. The region's coastal communities would experience climate damages in the decades ahead (Table 4). Several of the Southeast Asian countries are island-states or in low-lying river deltas. The Mekong river delta of Vietnam and many small islands in Southeast Asia are most at risk. The cost for protecting Southeast Asia against sea-level rise of more than half a meter is estimated to be US $300 billion (Preston et al, 2006). According to the *Asia Times*, 26 May 2007, Southeast Asia is possibly one of the most vulnerable areas in the global climate-change scenarios. Extreme climate events are expected to occur more frequently. The Philippines, Vietnam, Cambodia, Lao PDR, Thailand and Indonesia are among the countries identified as climate change 'hotspots' (Yusuf and Francisco, 2009). They are particularly vulnerable to some of the worst manifestations of climate change expected in the coming decades.

TABLE 4
Estimated Impact of Climate Change to Southeast Asia

Climate Change Impacts	Brunei	Cambodia	Indonesia	Lao PDR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Timor-Leste	Vietnam
Sea-level rise < 30 cm											✓[1]
Sea-level rise 30-50 cm[2]	✓	✓	✓[3]		✓	✓	✓	✓	✓	✓	✓[4]
Sea-level rise >50 cm	✓	✓	✓		✓[5]	✓	✓	✓	✓	✓	✓[6]
Temperature rise <2ºC[7]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Temperature rise 2-4ºC[8]	✓	✓[9]	✓[10,11]	✓[9]	✓	✓[9]	✓[12]	✓	✓[9,13]	✓[11]	✓[9]
Temperature rise >4ºC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Source: Preston, L B, R Suppiah, I Macadam and J Bathos 2006.
Notes:
1. About 69 – 91 percent of land area in Mekong Delta, Vietnam affected by sea-level rise during flood season (Wassmann et al, 2004).
2. About 29,808 km of shoreline affected in Southeast Asia with direct costs of US$226 million per year (Darwin, 2001).
3. About 34,000 km^2 of land area lost in Indonesia affecting 3.1 million people (UNEP, 2006).
4. About 86 – 100 percent of land area in Mekong Delta, Vietnam affected by sea-level rise during flood season (Wassmann et al, 2004).
5. About 7,000 km^2 of land area lost in Malaysia affecting about 500,000 people (IPCC, 2001).
6. About 40,000 km^2 of land area lost in Vietnam affecting 26.9 million people (UNEP, 2006). About 15 percent of dry land lost in Vietnam and 8 percent of GDP (Tol, 2004).
7. Large-scale damages to coral reef ecosystems in the region (Hoegh-Guldberg, 1999). Coastal southeastern Asia becomes suitable for malaria transmission (Rogers and Randolph, 2000). Epidemic potential for malaria, and dengue in Southeast Asia changes by +7 – +45 percent, and +24 – +47 percent, respectively (Martens et al, 1997).
8. About 4 – 8 percent of species extinct in tropical woodlands and forests (global estimate) (Tol, 2004). Population at risk for malaria in Southeast Asia declines by 1 million (van Lieshout et al, 2004). Number of people experiencing increase in water stress in Southeast Asia increases by 0 – 10 million (Arnell, 2004).
9. Number of people experiencing increase in water stress in Greater Mekong[4] increases by 0 – 105 million (Arnell, 2004).
10. US$64.5 billion in cumulative health costs associated with treatment of infectious disease in Indonesia; total climate change losses equivalent to US$766 billion in Indonesia (Asia Development Bank, 1994).
11. Vegetation biomass in southern Southeast Asia (Hadley Centre, 1999).
12. Change in runoff of -12 – +7 in Lake Lanao Reservoir and -12 – +32 in Angat Reservoir, Philippines (Jose and Cruz, 1999).
13. About 1.1 – 3.5 percent decline in Thailand's GDP (Mendelsohn et al, 1998).

[4]The Greater Mekong Subregion (GMS) comprises Cambodia, the People's Republic of China, Lao People's Democratic Republic, Myanmar, Thailand, and Vietnam.

3. CLIMATE CHANGE RESEARCH AND POLICY

Sustainable development remains a critical urban challenge. Unlike many developed countries, sustainable development is not particularly hot in Southeast Asia given the general desire to 'grow'. Most Southeast Asia countries still do not have much action on climate change and GHG emission even though 10 of the 11 countries have ratified the 1997 Kyoto Accord to the 1992 United Nations Framework Convention on Climate Change (Table 5). Equally, the United Nations Climate Change Conference in Bali, Indonesia, Dec 2007 has reiterated, among others, the need for enhanced action on climate change efforts. Economic development seems to remain the top priority on developing country government's agenda, including Singapore. None of these countries has mandatory obligations to reduce GHG emission. Public awareness and concern on climate change appear not as strong as those in the developed world. In Indonesia, the largest country in Southeast Asia, for example, climate change is perceived more as an international concern rather than a domestic matter (Williamson, 2007). In post-conflict countries such as Timor-Leste where up to 70 percent of its infrastructure has been destroyed during the violence, the pressing concerns are security and economic reconstruction to rebuild its infrastructure and strengthen government and civil institutions. Climate change is not seen as a priority in Timor Leste and not mentioned on the government website. The region has to urgently shift towards a sustainable development model of 'green growth paradigm'.

TABLE 5
Climate Change Actions

Climate Change Actions	Brunei	Cambodia	Indonesia	Lao PDR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Timor-Leste	Vietnam
Ratification of the 1997 Kyoto Accord to the 1992 United Nations Framework Convention on Climate Change		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
National climate change strategy or actions plan		✓[1]	✓[2]	✓	✓		✓[3]	✓	✓		
National climate change committee or inter-agency task force	✓	✓[4]	✓	✓[5]	✓		✓	✓	✓		
Development plan mentions climate change		✓	✓				✓	✓	✓		✓
Green building movement	✓		✓		✓		✓	✓	✓		✓
Green neighborhood								✓			

TABLE 5, *continued*

Climate Change Actions	Brunei	Cambodia	Indonesia	Lao PDR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Timor-Leste	Vietnam
Eco-city planning					✓			✓			
Study of vulnerability to climate change		✓	✓				✓[6]	✓			
Implementation of CDM		✓	✓	✓	✓	✓	✓		✓		✓
Urban planning policy for climate change				✓[7]	✓			✓			
Clean air policy	✓[8]		✓		✓		✓	✓	✓		
Energy efficiency policy			✓		✓		✓[9]	✓	✓		✓
Building control act for climate change			✓		✓			✓			
Promotion of renewable energy		✓[10]	✓	✓[11]	✓		✓	✓	✓		✓
Clean & renewable energy research and development			✓					✓			
Develop resilient water resource			✓[12]				✓	✓	✓		✓

Source: Country, city council, renewable energy and green buildings movement websites.

Notes:

1. The Ministry of Environment (2001) has developed the National Action Plan on Climate Change. In August 2003, CCCO started implementation of a new project, the National Adaptation Program of Action to Climate Change with financial support from GEF through UNDP.
2. Indonesia released the National Action Plan for Climate Change Mitigation and Adaptation at the end of 2007. The document still demands revision by related sectors, academics and experts. See *The Brunei Times*, 10 July 2008 http://www.bt.com.bn/en/opinion/2008/07/10/tackling_climate_change_the_finest_way.
3. Funded by USAID.
4. The Ministry of Environment has set up a separate office called Cambodia Climate Change Office (CCCO) in June 2003.
5. Science, Technology and Environment Agency has a key role to coordinate across all ministries and local authorities to manage the overall environment throughout Lao PDR.
6. An ADB climate change project in 1991 assessed Philippines' vulnerable sectors and areas to climate change including agriculture, water resources and coastal areas.
7. Pragmatic integrated transport plans for the main urban centre and the formulation of an overall urban transport policy including the possibility of mass public transport are high priority of Lao PDR government facing rapidly increasing volumes of motorized traffic in urban centers.
8. Brunei has national programs include improvements of transportation infrastructure to reduce traffic congestion, cogeneration power station to reduce emissions of pollutant gases, and full use of unleaded gasoline to reduce air pollution. http://www.wpro.who.int/NR/rdonlyres/64F00DEF-F568-4A03-8855-13C2958D0B4B/0/BRU.pdf.
9. Energy efficiency programs in the Philippines are directed by the Department of Energy and guided by an Energy Plan that currently covers the period from 2002 to 2011. See Renewable Energy and Energy Efficiency Partnership http://www.reeep.org/index.php?id=9353&text=policy-db&special=viewitem&cid=72.
10. Renewable Electricity Action Plan 2002–2012. See Renewable Energy and Energy Efficiency Partnership http://www.reeep.org/index.php?id=9353&text=policy-database&special=viewitem&cid=30.
11. A World Bank-assisted project in 1997 has demonstrated renewable energy technologies as off-grid electrification options to reduce inefficient use of fossil fuels in diesel generators in rural areas.
12. Solar energy desalination project in North Jakarta district.

Climate change, major drought and flooding are refocusing attention on the environment and sustainable development. Increasingly, more initiatives have been taken, particularly post-Agenda 21 and with international aid, for example, the International Council for Local Government Initiatives (ICLEI) Cities for Climate Protection in Southeast Asia and UN-HABITAT Sustainable Cities Program to make Southeast Asian cities more sustainable. Grants (technical assistance) and loans (for example, GEF funds) are the dominant type of project funding. Many cities in Southeast Asia, including medium-sized cities such as Penang in Malaysia now have sustainable development initiative. This is an encouraging development, especially as Roberts and Kanaley (2006, p437) pointed out, "Asia's future is urban. It is in developing sustainable cities." In this regard, ASEAN provides an important inter-governmental framework for regional cooperation on climate change and sustainable development. A milestone is the ASEAN Declaration on Environmental Sustainability signed by the country leaders at ASEAN 40th anniversary and 13th ASEAN Summit (Nov 2007) in Singapore. The Declaration recognizes the need to encourage the development of an ASEAN Climate Change Initiative and support the development of environmentally sustainable cities.[5] In the area of climate change, the following are stated in the Declaration:

- To work closely with the international community to better understand and adapt to the adverse impacts of climate change, including, in particular, the related issues of greenhouse gas emissions and carbon sinks;
- To agree that the pursuit of climate change and energy security policies should avoid introducing barriers to trade and investment;
- To intensify cooperation on the joint research, development and deployment of low emission technologies for the cleaner use of fossil fuels, recognizing that fossil fuels will continue to play a major role in our energy mix;
- To take concrete measures to promote the use of renewable and alternative energy sources such as solar, hydro, wind, tide, biomass, bio-fuels and geothermal energy, as well as, for interested parties, civilian nuclear power, while ensuring safety and safeguards that are of current international standards, and environmental sustainability throughout the full life cycle of production and use;
- To improve energy efficiency in key sectors of energy use through capacity building and information sharing of best practices in managing energy use and the adoption of appropriate technologies and practices;

[5] http://www.aseansec.org/21060.htm.

- To undertake effective measures towards open and competitive regional and international markets geared towards providing affordable energy at all economic levels to facilitate the adoption of energy-efficient and low-emission technologies.

While progress is being made, especially among countries with higher income, the state of sustainable urban development and climate knowledge in Southeast Asia remains largely patchy. There are major differences within and across countries. The countries with relatively low adaptive capacity include the poorer countries of Cambodia and Lao PDR while Thailand, Malaysia and Vietnam are countries with relatively high adaptive capacity (Yusuf and Francisco, 2009). International development agency project/program-based activities provide an important source. Many of these activities relate to capacity building, data gathering and policy development in specific project/program interest areas. They generally reflect specific project/program scope and are designed to improve project management and implementation rather than capacity development per se. Capacity development is absolutely pertinent to bringing change to Southeast Asian cities. Improving the effectiveness and cooperation between organizations in setting priorities and developing capacity that is less donor-driven and more demand responsive is needed. The knowledge gap is real.

Of the 28 planning schools in Southeast Asia, apparently none has teaching program on climate change. Education on planning for climate change is urgently required. Very few are having research on sustainable urban development. Many of the existing climate research are in the field of technologies, for example, air quality, water and energy such as fuel cells, bio-energy and bio-fuels. A focus on technology though common is too narrow for Southeast Asia. There are signs of change. In the face of rapid urbanization and global warming, the case for sustainable city research is strong and fast emerging as an important agenda. As Blakely (2007, p9) argues in the wider urban planning literature, "Sustainability is now firmly part of the lexicon of planning and is the best grounding for climate change research." Post-tsunami has seen the setting up of disaster risk management and geo-technology research center in Indonesia.

Several regional networks (for example, the Partnerships for Disaster Reduction Southeast Asia, the Asian Cities Climate Change Resilience Network) and research centers have been set up. More funding is being put into research on the environment, climate change and city including at the national level. Knowledge has become urgent as more and more Southeast Asian cities seek the development of a sustainable city for future urban living. LESTARI at the Universiti Kembangsaan Bahasa and National Hydraulic Research Institute of Malaysia (NAHRIM) Research Centre for Water Resources, Government of Malaysia, the latest regional water knowledge hub for climate change adaptation, and the National Environment Research Institute set up in 2007 at National University of Singapore, Singapore, are some examples of the new kind of interdisciplinary research institutions set up in Southeast Asia to research the issues of sustainable city.

Even private sector has joined the arena. For example, Siemens Singapore in April 2009 has set up a Siemens city of the future exhibition and solutions center to profile innovative solutions and technologies for city management of future smart, safe and mobile cities. New holistic and interdisciplinary research results on Southeast Asian sustainable urban development can be expected in the years ahead when the actors get into doing the interdisciplinarity and disseminate their findings. In the frontline of dynamic and unprecedented growth, urban research needs to break new ground, refocus on the interdisciplinary economic, social, technological/environmental issues of sustainable city, and seek holistic, integrated, multi-disciplinary solutions to the urban and climate challenges of Southeast Asian cities. The conventional 'business as usual' mode will not work; 'business unusual' suggests thinking outside the box—-thinking, approaching, organizing and also funding sustainable urban development research in new ways.

Even as individual countries and the regional body of ASEAN have declared the need for improving energy efficiency, use of clean energy technologies and renewable and research, only one country, Singapore, presently seems to have more activities on climate change and lead the region in seeking more regional efforts over this issue. Singapore has started to promote climate change related research and development after signing the Kyoto Accord in late 2006. It is master planning and developing an eco-city in China in partnership with the Chinese government. It is promoting water technology and renewable energy by investing in R&D, including the establishment of research institutes, provision of funding and test-bedding platforms to improve their performance and cost-effectiveness. It has set up an Energy Efficiency Singapore Program Office (E2PO) comprising members from the relevant government and research institutions. E2PO has developed a national plan to promote energy efficiency, comprising actions in several areas:

- Promoting the adoption of energy efficient technology and measures by addressing the market barriers to energy efficiency;
- Raising awareness to reach out to the public and businesses so as to stimulate energy efficient behavior and practices;
- Building capability to drive and sustain energy efficiency efforts and to develop the local knowledge base and expertise in energy management;

- Promoting research and development to enhance Singapore's capability in energy efficient technologies.

Energy production is a major consideration. Several other countries have also started to converge on renewable energy. Malaysia, the Philippines and Thailand have all established renewable energy strategies and targets. Malaysia, for example, has a Five Fuel Diversification Policy since 2000, a small renewable energy power program, Biogen program with a target (2005) of 5 percent or 500 mw of power capacity. The Philippines renewable energy policy framework 2003 includes a target (2003-2013) of 100 percent increase of renewable energy power capacity while Thailand's strategic plan for renewable energy development 2003 sets a target by 2011 of 9 percent renewable energy share in primary energy and 4 percent renewable energy power capacity.

Energy efficiency policy in Thailand appears one of the most advanced in ASEAN. The driver is the Thai government's vision to establish Thailand as the Regional Energy Centre for Southeast Asia. It has implemented a Strategic Plan for Renewable Energy Development. Solar, wind, biomass, biogas, hydro, bio-fuels, geothermal and fuel cells are included in the Strategic Plan as well as energy efficiency (Australian Business Council for Sustainable Energy, 2005). Its Department of Energy Development and Promotion and Energy Policy Office are pursuing activities such as consumer education, industrial energy audits, thermal/electricity energy efficiency demonstration projects and end-use studies. In the Philippines, the case of integrating GHG emission reduction and avoidance strategies into the city's operations of waste management, land use planning, transport improvement and building retrofits such as in the Cagayan de Oro, Philippines ICLEI project could serve as a promising practice for other cities (ICLEI, 2009). Cagayan de Oro is greening its energy supply and making demand-side improvements with the target to reduce GHG emissions by 10 percent against forecasted emissions growth.

There are increasing efforts, both commercially and promoted by government, to develop and expand bio-fuel production; bio-diesel from palm oil is especially favored. Although bio-fuel is often pitched as a sustainable energy source, there is concern that the rush to develop it may result in more destruction of old forests to clear the way for oil-palm plantations, contributing to the problem of slash and burn, and haze. There is also a regional shift towards more natural gas, which is desirable in terms of its lower carbon-dioxide emissions. By 2006, 78 percent of Singapore's electricity was generated by natural gas using highly efficient combined cycled technology, one of the highest in the world. But natural gas has its obstacles, including delays in constructing pipelines and issue with upstream production, which often releases carbon dioxide unless engineering measures are taken to re-inject the gas.

More hydropower is likely to be used, especially in the Mekong region. But, again there are environmental concerns as to the impact of the river damming on downstream river life and communities vulnerable to drought. Vietnam, in particular, is finding this a major problem, with its exceptionally dry seasons during the past two to three years, leading to low water levels in the reservoirs behind hydro-dams and competition in supply for farmers down river for rice irrigation and for power generation. Nuclear power has also emerged as a serious possibility in several countries, including Vietnam, Indonesia, Thailand and Myanmar. Again, there are many issues here, ranging from economic feasibility to safety and weapons-proliferation concerns that require research and policy development to address. Policies and mechanisms conducive to knowledge dissemination and technology transfer among countries including between advanced developed countries and Southeast Asia are clearly required.

4. URBAN PLANNING INTERVENTION

Even though global climate change awareness has been around for some time, it is only in recent years that cities and urban planners in the region appear to consider the environment in their planning of competitive and livable cities. Many countries have begun to address climate change issues in different ministries. Some have even formulated national climate change policy (see Table 5). Increasingly, environmental sustainability is mentioned in development plans. In 2008, ASEAN presented the first ASEAN Environmentally Sustainable City award to 10 cities/townships/districts in ASEAN that have made exemplary effort towards environmental sustainability. These 10 cities are: Brunei Darussalam: Temburong District, Cambodia: Municipality of Phnom Penh, Indonesia: Palembang City, Lao PDR: Luang Prabang District, Malaysia: North Kuching City Hall, Myanmar: Taungyi City, Philippines: Puerto Princesa City, Singapore: South West Community Development Council, Thailand: Bangkok City, Vietnam: Ha Long City. By and large, climate change is not mainstreamed in development plans.

Mainstreaming of climate change in development planning is critical. UN-HABITAT (2007b) has reiterated that urban planning is important in managing climate change because well-planned cities provide a better foundation for sustainable development than unplanned cities. Both adaptation and mitigation actions of environmental change require urban planning. Among others, urban planning and development control could help to mitigate the urban heat island effect by creating open spaces and parks as heat sinks in urban areas, reduce the urban ecological footprint by planning for more efficient, compact and mixed use city forms and a shift to public transport-based movement. In the urban and planning literature, there is a gradual shift of focus on mitigation actions to a concern with longer term adaptive measures of, for example, preventing flooding and landslides, protecting or relocating vulnerable settlements, improving drainage and preventing new developments in areas likely to be affected by sealevel rise or floods, among others. The integrative planning of a future climate regime has significant implications for Southeast Asian urbanization, especially in mega-cities and vulnerable areas. Raising the policy profile of climate change within the context of sustainable development is crucial in realizing the vision of a sustainable Southeast Asia.

Land use change has impact on the carbon balance of ecosystems. Practices that detract environmental sustainability cannot be promoted. At its simplest, the common planning typology of land use zoning determines land cover types. Land cover types affect energy and water consumption as well as waste and traffic production and GHG emissions (Pauleit and Duhme, 2000). In many developing countries, local authorities lack the mandate and human capacity to handle urban planning and its enforcement mechanisms. As the Asian Development Bank (2008) concluded in its review of managing Asian cities, capacities are deficient in key areas of urban management, economic and social planning and environmental management in many Asian cities, Southeast Asian cities included. The comparative newness and unprecedented scale of urbanization has accentuated the problem. Improved technical competence in urban planning is required at all levels of government.

Beyond the demand for professional urban planning education, most developing countries in the region are facing the problem of weak capacity of local or municipal government. Visions are lacking. Planning is generally short-term, physically oriented and unable to respond effectively to change. Newer and more innovative planning approaches are in order. There is also the issue of plan implementation. Plans that reflect sustainable development principles carry no meaning if they are not implemented. There is an urgent need to strengthen the institutional capabilities that are prerequisite to effective plan implementation. More attention has to be given to the functioning of the planning system and as such, to legislation, regulations and processes that are out of date or are insufficiently reformed to be able to deal with the major challenges of the 21st century. Strong government leadership is indispensable, particularly where there is a need to create policy conditions and a multi-stakeholder process for plan implementation. Proper modalities should also be developed to monitor plan implementation and ensure its continued relevance to changing conditions and dynamics.

Well-planned cities are not only efficient but also make sustainable use of resources including space, energy and water. Take Singapore. The strong state commitment to planning has transformed the city from 'third world to first world' (Lee, 2000; Yuen 2004). Its comprehensive, integrative planning has led to the efficient use of space, clustering many people in a relatively smaller land area, often through high-rise high-density settlements. Research has indicated that denser urban areas emit less radiant heat energy per parcel than do more expansive developed areas (Stone and Rodgers, 2001). The co-location of high-rise, high-density urban form, services and employment is purposefully designed to configure a hierarchy and location of community facilities that reduce or minimize travel by private car and enhance walking and usage of public transportation while enhancing quality of life. Its deliberate greening policy at the building, neighborhood and city levels gives careful consideration to the relationship between the built and natural environments, creating a garden city and increasing the cooling potential of its built-up areas. Additionally, since 2007, green buildings have been encouraged. These buildings adopt various energy efficiency ways and designs to minimize impact on climate change, including the use of recycled or recyclable materials for construction.

Singapore is building its first eco-friendly precinct of 700 public housing flats, expected to complete by 2011, to promote sustainable green living. There will be more greenery provision, which is expected to lower the surrounding temperature by as much as 4°C. Solar panels on the roof of buildings will power the common corridors, improving energy resource utilization and saving 80 percent of the energy used. On the industrial front, it has built an industrial park on Jurong Island planned on the principle of industrial symbiosis where the waste or by-product of one enterprise becomes the resource or input of another. While Singapore may have its unique characteristics, its strong commitment to planning bears testimony to planning in action. In the era of climate change, cities must be planned to develop sustainably from the start.

More than ever, sustainable urban development is now the key theme of urban planning and is fundamental for climate change policy. Energy efficient buildings and built form, renewable energy sources, climate responsive design and standards together with open space and green areas are important to ensure a sustainable neighborhood. Cities can take proactive measures to reduce emissions from vehicles. Motor vehicles — a major source of carbon dioxide emissions — are set to increase in Southeast Asian cities. In per capita terms, car ownership is still low. But, in large urban areas, growing car ownership continues to congest cities, pollute the atmosphere and endanger community health through vehicle exhaust. Alternative urban form aside, better public-transport systems, from buses to rail and sustainable transport options are clearly critical. Bangkok, Thailand, long notorious for traffic jams and air pollution, is now benefiting from its light rail and underground rail system as well as stricter standards and controls on gasoline quality. In Vietnam, the fastest-growing economy in the region, there are plans for mass-transit systems for the large and fast-growing cities of Hanoi and Ho Chi Minh.

Urban planning, though essential is not sufficient, in addressing climate change. Population, economic development, technology advancement and government policies on energy and environment are key drivers of GHG emissions and interlinked in a complex web of interactions. Energy production and use, for example, are sensitive to changes in the climate. The climate change effects on energy supply and demand will depend not only on climatic factors but also on the patterns of economic growth, land use, population growth and distribution, technological change and social and cultural trends that shape individual and institutional actions. Understanding these major driving forces will enable the setting of corresponding adaptation strategies and policies to address climate change. To succeed, climate proofing requires concerted action across all sectors. This includes cooperation and joint programming on population, economic growth, GHG emissions control, R&D, application of clean technologies, renewable energy and eco-city policies to ameliorate GHG emissions, among others.

Collaboration across planning, enforcement and compliance regimes can strengthen the integration of environmental concerns into the wider development agenda. As demonstrated by the Singapore experience, the government plays a critical role in the coordination approach and creating policies, incentives and disincentives and plans that encourage sustainable urban development, in environmental education and training, and enforcement of policies and regulations. To improve the resilience of Southeast Asian cities to climate change, it is imperative to also implement institutional strengthening and capacity building to ensure that the institutions and human capital have the knowledge on climate change and are able to make effective decision, allocate resources and manage risk and implementation.

5. CONCLUSION

The challenge of climate change in Southeast Asia is real and urgent. Climate change is likely to amplify some of the existing urban and environmental stresses and vulnerabilities of its urban communities, many of which are living in coastal and low-lying areas and rapidly expanding mega-cities. A business-as-usual scenario is unlikely to support a sustainable Southeast Asia. Measured against this situation, Southeast Asian responses to date have been largely inadequate even though several important steps have been taken and a number of essential foundations, both at country and regional levels, have been established for further action. For example, ASEAN leaders have recently signed the Declaration on Environmental Sustainability and the ASEAN cooperation in environment has established a common agenda and forged consensus on some policy goals for sustainable development as well as action to address trans-boundary haze pollution, nature conservation and biodiversity, marine and coastal environment problems. Another milestone is the establishment of the ASEAN sub-regional climate review meeting in 2000 to closely monitor the weather condition especially during the dry seasons to prevent and mitigate the damages from recurrent fires and haze. Yet, its forests, rivers and land remain environmentally vulnerable.

While there is no standard model solution and sustainable development may be more complicated than the commonly acknowledged economic, social and environmental dimensions in practice, the importance of sustainable development as the guiding principle to climate proofing cannot be neglected. The mainstreaming of climate issues into national strategies and development planning is crucial. In all cases, planning offers an important entry point, shaping urban form in very particular ways with implications on climate change. The proactive development of newer and innovative planning is essential for better environmental management and sustainable development in this vein. The emergence of planning's central role has reinforced the need for truly cross-sectoral integration to be in place as well as capacity development so as not to overburden the already weak implementation capacity.

References

Arnell, N. (2004) "Climate change and global water resources: SRES emissions and socio-economic scenarios." *Global Environmental Change*, 14, 31-52.

Asian Development Bank (ADB) (1994) *Climate Change in Asia: Executive Summary*, Manila, ADB.

________(2008) *Managing Asian Cities*, Manila, ADB.

Asia-Pacific Energy Research Centre (APERC) (2006) *APERC Energy Demand and Supply Outlook 2006*.

Australian Business Council for Sustainable Energy (2005) *Renewable Energy in Asia: The Thailand Report*, August.

Blakely, E. J. (2007) "Urban planning for climate change." *Lincoln Institute of Land Policy Working Paper*.

Darwin, R. F., and Tol, R. S. J. (2001) "Estimates of the economic effects of sea-level rise." *Environmental and Resource Economics*, 19, 113-129.

Hadley Centre (1999) "Climate change and its impacts: stabilisation of CO2 in the atmosphere." *Hadley Centre for Climate Prediction and Research*, Met Office, UK, http://www.met-office.gov.uk/research/hadleycentre/pubs/brochures/B1999/climate_web.pdf.

Hoegh-Guldberg, O. (1999) "Climate change, coral bleaching and the future of the world's coral reefs." *Marine and Freshwater Ecology*, 50, 839-866.

ICLEI (2009) *International Council for Local Environmental Initiatives: Cities for Climate Protection in Southeast Asia*, http://www.epa.gov/usctcgat/file/toolmanager/O86C299F62935.pdf.

International Energy Agency (2002) *World Energy Outlook 2002*, IEA/OECD, Paris.

IPCC (2001) *Climate Change 2001: Impacts, Adaptation and Vulnerability*. McCarthy, J., Canziani, O., Leary, N., Dokken, D., and White K. (editors) Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme. Cambridge University Press.

Jones, G. W. (2002) "Southeast Asian urbanization and the growth of mega-urban regions." *Journal of Population Research*, 19(2), 119-136.

Jones, C. D., Cox, P. M., Essery, R. L. H., Roberts, D. L., and Woodage, M. J. (2003) "Strong carbon cycle feedbacks CO2 and sulphate aerosols." *Geophysical Research Letters*, 30, doi:10.1029/2003GL01686.

Jose, A. M., and Cruz, N. A. (1999) "Climate change impacts and responses in the Philippines: Water Resources." *Climate Research*, 12, 77-84.

Lee, K. Y. (2000) *From Third World to First: The Singapore Story, 1965-2000*. New York: HarperCollins.

Martens, W. J. M., Jetten, T. H., and Focks, A. D. (1997) "Sensitivity of malaria, schistosomiasis and dengue to global warming." *Climatic Change*, 35, 145-156.

Mendelsohn, R., Morrison, W., Schlesinger, M. E., and Andronova, N. E. (1998) "Country-specific market impacts of climate change." *Proc., IPCC Asia-Pacific Workshop on Integrated Assessment Models*, 10-12 March, 1997, Tokyo, Japan, http://crga.atmos.uiuc.edu/publications/market_impact/MarktImp.PDF#search=%22Country-specific%20market%20impacts%20of%20climate%20change%22.

Pauleit, S., and Duhme, F. (2000) "Assessing the environmental performance of land cover types for urban planning." *Landscape and Urban Planning*, 52(1), 1-20.

Preston, L. B., Suppiah, R., Macadam, I., and Bathos, J. (2006) *Climate Change in the Asia/Pacific Region*, Consultancy Report Prepared for the Climate Change and Development Roundtable, CSIRO Marine and Atmospheric Research.

Roberts, B., and Kanaley, T. (2006) *Urbanisation and Sustainability in Asia*, Manila: ADB.

Rogers, D. J., and Randolph, S. E. (2000) "The global spread of malaria in a future warmer world." *Science*, 289, 1763-1766.

Stone, J. B., and Rodgers, M. O. (2001) "Urban form and thermal efficiency: How the design of cities influences the urban heat island effect." *Journal of the American Planning Association*, Spring, 186-198.

The Brunei Times (2008) from the country report presented by the Department of Public Works of Indonesia during the COP Conference of 13 Parties in Bali in November 2007, http://www.bt.com.bn/en/opinion/2008/07/10/tackling_climate_change_the_finest_way, (July 10, 2008).

Tol, R. S. J. (2004) "The Double Trade-Off Between Adaptation and Mitigation for Sea-Level Rise: An Application of FUND." Working Paper FNU-48, Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Sciences, Hamburg, Germany, http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/slradaptmitigatewp.pdf.

UNEP (United Nations Environment Programme) (1999) *Global Environment Outlook 2000*. London: Earthscan.

________ (2006) *Geo Year Book 2006: An Overview of Our Changing Environment*. Early Warning and Assessment, United Nations Environment Programme, Nairobi, Kenya, http://www.unep.org/geo/yearbook/yb2006/PDF/Complete_pdf_GYB_2006.pdf, Population estimates are based upon 2050 projections.

United Nations (2004) *World Urbanization Prospects: The 2003 Revision*, United Nations, Department of Economic and Social Affairs, New York.

UN-HABITAT (2003) *Water and Sanitation in the World's Cities: Local Action for Global Goals*, London: Earthscan.

________(2007a) *Enhancing Urban Safety and Security: Global Report on Human Settlements 2007*, London: Earthscan.

________(2007b) *UN-HABITAT pitches for urban planning*, Bonn, http://www.unhabitat.org/content.asp?cid=4836&catid=550&typeid=6&subMenuId=0.

Van der Werf, G. R., Randerson, J. T., Collatz, G. J., Giglio, L., Kasibhatla, P., Arellano, A., Olsen, S., and Kasischke, E. S. (2004) "Continental-scale partitioning of fire emissions during the 1997 to 2001 El Niño/La Niña period." *Science*, 303, 73-76.

Van Lieshout, M., Kovats, R. S., Livermore, M. T. J., and Martens, P. (2004) "Climate change and malaria: Analysis of the SRES climate and socio-economic scenarios." *Global Environmental Change*, 14, 87-99.

Von Einsiedel, N. (2004) "Strengthening local government capacities in urban planning and finance: Lessons from the East Asian city development strategies," in Freire, M., and Yuen, B., editors, *Enhancing Urban Management in East Asia*, Ashgate: Aldershot, p 159-169.

Wassmann, R., Hien, N. X., Hoanh, C. T., and Tuong, T. P. (2004) "Sea level rise affecting the Vietnamese Mekong Delta: Water elevation in the flood season and implications for rice production." *Climatic Change*, 66, 89-107.

Williamson, L. (2007) *BBC News*, 2 May 2007, http://news.bbc.co.uk/2/hi/asia-pacific/6610973.stm.

Yuen, B. (2004) "Planning Singapore growth for better living" in Freire, M., and Yuen, B., editors, *Enhancing Urban Management in East Asia*, Ashgate: Aldershot, p 55-70.

Yusuf, A. A., and Francisco, H. (2009) Climate Change Vulnerability Mapping for Southeast Asia, IDRC.

PART 4

Economic and Social Aspects of Climate Change and Cities

CHAPTER 22

Does Climate Change Make Industrialization An Obsolete Development Strategy for Cities in the South?

Le-Yin Zhang*

Summary

This paper attempts to explore the implications of climate change for economic development strategies in cities in the South. In particular, it examines whether climate change makes industrialization an obsolete development strategy for these cities. It starts by examining the effects of climate change and the challenges posed for the cities concerned, followed by a discussion of the role of industrialization in economic development and climate change. It then investigates how these issues affect Southern cities by considering the experiences of Shanghai, Mumbai and Mexico City. In conclusion, the paper hypothesizes that climate change will make industrialization a more, not less, important development strategy, even for those cities that are currently affected by pre-mature deindustrialization.

*Corresponding author: le-yin.zhang@ucl.ac.uk

1. INTRODUCTION

In a world of rapid urbanization and global integration, climate change represents only one of the many challenges that cities in the South have to grapple with in the coming decades. It is nevertheless a fundamentally important challenge for these cities because failing it will not only diminish their own long-term prospects, but also let the world seriously down.

This is for several reasons. First, developing countries already produce more than half of the total global emissions, and this share is rising fast. Non-OECD emissions of carbon dioxide exceeded OECD emissions by 7 percent in 2005, and are projected to exceed those from the OECD countries by 72 percent in 2030 (International Energy Agency 2008). Therefore, although developing countries are under no formal obligation at the present to mitigate, this is bound to change. Second, any prospective changes in terms of mitigation obligation will primarily affect cities in the South, as they embody a majority of the economic activities there.[1] Third, concerns about climate change have the potential to bring forward a new energy system and, associated with it, a new international trading environment. If some of the legislative changes (e.g. cap-and-trade scheme in USA) currently proposed are to become reality, this could substantially alter the comparative advantage of developing countries, with great impact on cities in their role as bridgeheads of international trade.

Therefore climate change can affect and be affected by economic development pathways in a fundamental way. This is why climate change has to be mainstreamed through economic development strategies (Zhang 2008). Accordingly, this paper attempts to explore the implications of climate change (and its impact) for economic development strategies in cities of developing countries. In particular, it examines whether climate change makes industrialization a less viable development strategy for these cities, since industrial activities are a major source of emissions in the South (see Figure 2).

The paper starts by examining the effects of climate change and the challenges that it poses for developing cities, especially in terms of industrialization. This is followed by a discussion of the role of industrialization in economic development, and the relationship between industrialization and climate change issues, highlighting tensions as well as synergy between the two. The paper then examines how these issues are affecting developing cities by considering the experiences of Shanghai, Mumbai and Mexico City. It concludes that industrialization still represents a viable and, to some extent, indispensable development strategy for these cities in the context of climate change, even for those that are affected by pre-mature deindustrialization.

[1]Urban-based economic activities account for up to 55 per cent of gross national product (GNP) in low-income countries, 73 per cent in middle-income countries and 85 per cent in high income countries (UN-HABITAT 2006).

2. CLIMATE CHANGE AND DEVELOPING COUNTRIES

2.1 The Challenge of Climate Change

Climate change mitigation poses a potentially serious challenge for developing countries. As Table 1 shows, although tCO_2-eq emissions per capita in these countries were only one-fourth of those in Annex I countries by 2004, they had already exceeded the so-called 'emissions budget' by a factor of 4 and were responsible for more than half of the total emissions.[2] On the other hand, GHG emissions per unit of GDP were 50% higher in non-Annex-I countries, which means that there is significant scope for mitigation in developing countries. Moreover, even if there is no immediate obligation to mitigate, there is growing economic incentive to do so in the context of an emerging global carbon market and the Clean Development Mechanism under the Kyoto Protocol (Zhang 2008).

However, since their population and economic growths are generally faster than in developed countries, faster reductions in emissions intensity will be needed in order to offset these growths so as to achieve de-carbonization. As the Kaya Identity suggests (see Equation 1), this can be achieved by either reducing energy intensity (i.e. energy/GDP), or reducing the carbon intensity of energy (i.e. CO_2 emissions /energy). Key strategies include improving energy use efficiency, industrial restructuring (i.e. reducing the weight of energy-intensive economic activities) and energy switch (i.e. reducing the weight of emission-intensive fuels).

Kaya Identity (Nakicenovic et al. 2000):

Equation 1: CO_2 emissions = Population X (GDP/Population) X (energy/GDP) X (CO_2 emissions/energy)

Equation 2: CO_2 emissions = Population X (GDP/Population) X (CO_2/GDP)

TABLE 1
Distribution of global GHG emissions (2004)

Grouping	tCO_2 eq/ cap	$KgCO_2$ eq/ $US\$GDP_{ppp(2000)}$	Share in Global Totals (%)		
			Population	GDP	Emissions
Annex I countries	16.1	0.683	19.7	56.6	46.4
Non-Annex I countries	4.2	1.055	80.3	43.4	53.6

Source: Rogner et al. 2007, p.106, Figure 1 .4a and Figure 1 .4b. a: all Kyoto gases including those from land-use.

[2]The Third Assessment Report (Banuri et al 2001, p. 89) notes that stabilization of CO_2 in the atmosphere at 450 ppm would require limiting global carbon emissions to about 3 billion tons by 2100, equivalent to 0.3 tonne of carbon per capita. The last is equivalent to 1.1 metric tons of carbon dioxide.

On the other hand, developing countries face an even greater challenge in adaptation. This is principally concerned with reducing vulnerability and developing adaptive capacity (Burton, Diringer, and Smith 2006), although by definition adaptation should also aim to exploit the beneficial opportunities. When defined as "the likelihood of injury, death, loss, disruption of livelihoods or other harm" (Eriksen and O'Brien 2007, p.338), vulnerability inevitably affects populations whose livelihood or wellbeing is already undermined by high incidence of poverty. However, developing countries are more at risk also because of their geography, greater reliance on agriculture and lower adaptive capacity (Burton, Diringer, and Smith J. 2006; McCarthy et al. 2001; World Bank 2008). This places premium on non-agricultural productive activities and factors that strengthen their adaptive capacity, which include economic resources, technology, information and skills, infrastructure, institutions and equity (Smit et al. 2001)—in other words, the products of industrialization.

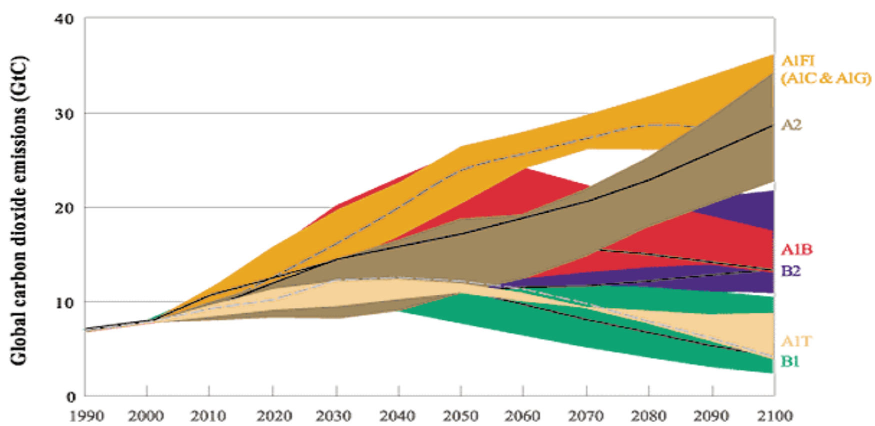
Thus developing countries need to take action in both mitigation and adaptation, aiming at reduction of emissions, reduction of poverty and vulnerability, and the strengthening of adaptive capacity. What does this mean for their economic development strategies?

2.2 The Implication For Economic Development in the South

The Special Report on Emissions Scenarios (SRES) (Nakicenovic et al. 2000) is relevant here. Guided by the Kaya Identity and building upon a common set of driving forces, including global population growth, economic development, technological diffusion, energy systems and land use, and assuming that no specific climate policies are implemented, the SRES outlines a set of four alternative scenario 'families' comprising 40 SRES scenarios. These scenarios indicate a wide range of CO_2 emission possibilities, ranging from less than 10 $GtCO_2$ to almost 35 $GtCO_2$ by 2100 (see Figure 1). The corresponding CO_2 concentration and global mean temperature increase (from 1990 to 2100) varies respectively from 500 to 1000 ppm and from 1.3ºC to 5.8 ºC, with the B1 scenario offering the lowest emissions. The drivers of the six illustrative scenarios are summarized in Table 2.

Figure 1 and Table 2 demonstrate a striking range of future possibilities. First, with everything else being equal, the A1 scenario, characterized by fast economic growth and population growth, could either lead to extremely high emissions or intermediate to low emissions, depending on the nature of the energy systems. Second, combining a service-based economy with cleaner energy produces B1, a scenario of very low emissions (lower than the level of 1990). Third, a combination of intermediate growth rates for the economy and population, and lower degree of global convergence would result in B2, characterized by relatively low emissions level, which is nevertheless higher than the level of 1990. Finally, the worst scenario would be A2, characterized by slow economic growth, fast population increase, less global convergence and very high emissions level. These contrasting scenarios point to one conclusion: the rate of economic growth is not the decisive factor for mitigation. Much will depend on the kind of energy systems developed and the economic structure.

FIGURE 1
Emissions Scenarios



Source: Nakicenovic et al. 2000, Figure TS-8. Each colored band shows the projected emissions of the six illustrative scenarios.

However, it would be mistaken to conclude from the SRES that developing economies should bypass industrialization or pursue de-industrialization at all costs. This is true despite the fact that industry is a major source of emissions. Industry accounts for 19.4% of global GHG emissions in 2004, and including energy supply increases industry's share to more than 40% of total emissions (IPCC 2007).

Moreover, the share of industry related emissions is even higher in developing countries. According to Price et al (2006), the SRES divided all emissions under four headings, namely industry, building, transport, and agriculture. Analysis of the detailed non-agricultural emissions data shows that the share of industry in non-agricultural emissions declined from 55.4% in 1971 to 49.8% in 2000 in these countries. However it is projected to rise to 51% in 2020 under scenario A1 and 51.9% under scenario B2 (see Table 3 and Figure 2).

TABLE 2
Emissions Scenarios and Drivers

Illustrative Emissions Scenarios	Key Drivers Of Emissions					
	Economic Growth	Economic Structure	Population Growth	Global Convergence	Energy Systems	
A1	Fast		Peaks in mid-21^{st} century, then declines	Fast	A1FI	Fossil energy intensive
					A1T	Non-fossil energy sources
					A1B	Balanced energy sources
A2	slow		Continuously increasing	slow		
B1	fast	Towards a service and information economy	Same as A1		Cleaner technology	
B2	Inter-mediate		Similar to A2, but at lower rate	Slower, more diverse than B1 and A1		

Source: Own elaboration on the basis of Nakicenovic et al. 2000, p. 22

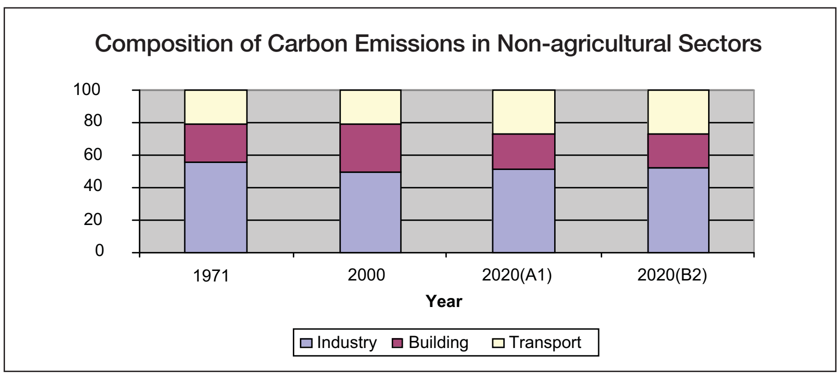
TABLE 3
Historical and Projected Non-Agricultural GHG Emissions by Developing Countries

Year	CO_2 Emissions (MtC)				Industry's Share of Total (%)	Developing Countries' Share in Total Non-Agricultural Emissions
	Industry	Building	Transport	Total		
1971	288	127	105	520	55.38	14.3
2000	1016	593	430	2039	49.83	34.5
2020 (A1)	3147	1361	1668	6176	50.96	53.2
2020 (B2)	2001	833	1019	3853	51.93	44.0

Source: Price et al. 2006. Own calculation. 2020 (A1) and 2020 (B2) represent respectively projections for SRES A1 and SRES B2 scenarios. Developing countries here include: centrally planned Asia, other Asia, Latin America, Sub Saharan Africa, and Middle East/North Africa.

Interestingly, the data (see Table 3) show that high industrial emissions in developing countries does not mean high share of global non-agricultural emissions by these countries. Indeed, the data show that, under scenario B2, although industry's share is as high as 52% in total non-agricultural emissions in 2020, these countries' share in total emissions could be as low as 44%. This is *prime facia* evidence that increased industrial emissions, a likely outcome of industrialization, do not have to mean high emissions for developing countries. In other words, there is no reason to think that industrialization will become less viable because of the need for CO_2 mitigation.

FIGURE 2
Importance of Industry-Related Emissions



Source: Table 3.

Having said this, there are other important reasons why industrialization cannot be abandoned as a development strategy. We explore this below.

3. INDUSTRIALIZATION AS AN ECONOMIC DEVELOPMENT STRATEGY FOR SOUTHERN CITIES

3.1 Why Industrialization?

According to Martinussen (1997), economic development refers to the process whereby the real per capita income of a country increases over a long period of time while simultaneously poverty is reduced and the inequality in society is generally diminished, or at least not increased. It is characterised by the structural transformation of the economy, or systematic changes in the allocation of factors of production and in improved techniques of production (Meier 1995:7). Industrialization, changes in demand and trade patterns, and urbanization are key aspects of such changes (Kuznets 1966; Syrquin 1988). A principal objective of any economic development strategy is to enhance the prospects for sustained economic growth, poverty reduction and structural transformation.

Industrialization, a process in which the share of industry (especially manufacturing) in both national income and employment increases in a country (Dasgupta and Singh 2006: 18), has traditionally played an important role in the economic development of almost every country (Chenery, Robinson and Syrquin 1986). Indeed, it distinguishes three stages in the process of their economic development: 1) primary production, when the production of primary goods- typically agricultural products- dominates the economy; 2) industrialization; and 3) developed economy, characterized by de-industrialization, the process when manufacturing's share in employment and then in GDP declines while the weight of services increases. During the course of industrialization, per capita income was found to rise from $400 to $2100 in 1970 dollars (equivalent to a change from $1,734 to $9,127 in 2007 dollars) in a selection of 38 significant economies.[3]

The process of industrialization is the most dynamic phase in the course of development, characterized by fast economic growth and technological progress, shift of resources from less to more productive activities and the building-up of the so-called 'social overhead' (i.e. basic infrastructure) (Young 1928; Kaldor 1966; Kaldor 1978). Many of the benefits of industrialization derive from the economies of scale uniquely associated with the manufacturing industry. The Kaldor's growth laws state:

- There exists a strong positive correlation between the growth of manufacturing output and the growth of GDP;
- There exists a strong positive correlation between the growth of manufacturing output and the growth of productivity in manufacturing
- There exists a strong positive relationship between the growth of manufacturing output and the growth of productivity outside of manufacturing (Thirlwall 2003)

[3]The 2007 amounts are calculated by using the GDP deflator provided on http://www.measuringworth.com/uscompare/ .

Moreover, industrialization is also an effective means for poverty reduction (Fukunishi et al. 2006). Cross-country experiences have shown that, to lift a large number of people out of poverty, one of the essential ingredients is to provide the poor with the opportunities to use their most abundant asset, namely labour (World Bank 1990, p. 51). In this regard, export-oriented industrialization is particularly effective, as it enables the exploitation of a market much larger than the domestic market, and creates jobs for a significant number of semi-skilled workers. It also has positive impact on distribution.

Industrialization could also fundamentally strengthen adaptive capacity by diversifying the economy and promote socio-economic features that strengthen adaptive capacity. One of the most interesting works in this area is a study by Roberts & Parks (2007). From analyzing a universe of more than 4,000 climate-related disasters across the world over the past two decades, these authors found that, when other factors are held constant, national poverty explained virtually none of the trends in deaths and homelessness. Instead, they found that people living in more urbanized nations were less likely to be killed, made homeless, or affected by climate related disasters than people living in more rural nations. Furthermore, a narrow export base explained about 1/3 of homelessness, from 1/7 to 1/3 of deaths, and about 40% of national patterns in who were affected by climate-related disasters. Since industrialization effectively increases the diversity of exports and strengthens urbanization, it can in turn reduce some common causes of vulnerability.

The above discussion demonstrates that industrialization remains a viable and important development strategy in the context of climate change. Despite this connection, some metropolitan cities in developing countries are already experiencing de-industrialization.

3.2 De-Industrialization

De-industrialization, evidenced by the fall in the share of manufacturing employment or an absolute fall in such employment (Dasgupta and Singh 2006), has both demand-side and supply-side causes (Rowthorn and Ramaswamy 1999). The experiences of London and Glasgow (Graham & Spence 1995; Lever 1991) demonstrate that two other factors are influential in the de-industrialization of metropolitan economies. First, competition for increasingly expensive real-estate could drive manufacturing activities out of the urban centre. Second, mis-guided policy attempts to de-congest established urban areas have similar effects. However, de-industrialization has predictable and predominantly negative consequences for low-income economies. It generally slows down overall productivity rise (i.e. economic growth and income rises) and causes unemployment and dereliction. It affects the semi-skilled labours most strongly, but also has wider repercussions around the economy. The crux of the matter is that such negative effects can not be compensated in low-income economies by the growth of other productive economic activities (e.g. knowledge-based and high-value added services) due to the lack of requisite skills and other kinds of capital.

Unfortunately, however, many developing countries are apparently undergoing de-industrialization while still at a low level of development (with a per capita GDP of around US$3000). Dasgupta and Singh (2006) describes this as "pre-mature de-industrialization". They identified two paradigms of de-industrialization since the 1980s: 1) the Indian type, where manufacturing employment is not expanding in the formal sector, but is growing within a large informal sector, and there is nevertheless expansion of manufacturing products. 2) The Latin American and African type, where contraction in manufacturing stops the economy from achieving its full potential of growth, employment and resource utilization. In the context of climate change, since manufacturing produces the material inputs for infrastructure (and for construction), pre-mature de-industrialization would reduce these countries' ability to develop infrastructure and more generally adaptive capacity.

3.3 The Way Out: Industrialization Coupled with De-Carbonisation

The above analysis suggests that there is synergy as well as tension between industrialization and climate change policy goals. While industrialization accelerates productivity and technological changes, reduce poverty and vulnerability, and facilitates the development of adaptive capacity, industry presently also produces a large amount of emissions. So what is the way out?

The Kaya Identity indicates that in order to retain the benefits of industrialization, the only way out is de-carbonization (i.e. the reduction of emissions intensity). This means that industrialization has to be combined with de-carbonisation to remain a viable economic development strategy.

Difficult as this may sound, de-carbonizing industrialization is probably more feasible than it appears. An important insight in the clean industrial production literature is that "new paths are always pioneered outside the dominant regions." (Robins and Kumar 1999, p.78). Such precedents include the American invention of mass production of automobiles and the Japanese pioneering of lean manufacturing. On the other hand, existing energy research suggests that emissions reduction depends on technological progress, retirement of inefficient technologies, changes in the structure of energy systems and patterns of energy services (Nakicenovic et al. 2006), all of which are enhanced by industrialization. This explains why developing countries are projected to continue to reduce energy intensity more quickly than developed countries because of the greater scope for technological advancement and improvement in energy use (IEA 2007).

The decarbonization of industry, while still in its infancy, is indeed already happening. For example, a study by Chandler et al. (2002) of mitigation experiences in six large developing countries (Brazil, China, India, Mexico, South Africa and Turkey) shows that efforts undertaken by these countries, often unrelated to climate policies, have reduced their emissions growth over the past three decades (1970s-1990s) by approximately 300 million tons a year. In particular, energy intensity started to fall from 1995 in India and declined by an average of 4% per annum during 1977-1997 in China. More importantly, these countries have significant scope for further mitigation: experts estimated that India could reduce projected emissions over the next 30 years by nearly one-quarter for less than $25 per ton of carbon equivalent. Another encouraging sign is that, according to a recent HSBC report (Robins, Clover and Singh 2009), it is China and South Korea, not USA, that lead the green investment league table in their fiscal stimulus packages in response to the on-going global financial turmoil started in 2007-08. The Chinese investment is more than twice as large as the USA's.

In conclusion, we have reasons to hypothesize that climate change does not make industrialization an obsolete development strategy for cities in the South. On the contrary, it may even make it more important than ever before. This is because, in comparison with de-industrialization, decarbonising industrialization has much greater potential to reduce emissions intensity, to reduce poverty and vulnerability, and to strengthen adaptive capacity in these cities. This is summarized in Table 4.

TABLE 4
Summary of Strategies and Their Potentials

Strategies and Outcomes	Potential to		
	Reduce Emissions Intensity	Reduce Poverty and Vulnerability	Strengthen Adaptive Capacity
De-industrialization	M	L	L
Decarbonising industrialization	H	H	H

Source: Own elaboration. Note: H = High; M = Medium; L= Low.

4. EVIDENCE FROM THREE CITIES

In this section, an attempt is made to examine how the issues raised above are affecting Southern cities with case studies of Shanghai, Mumbai and Mexico City.

To start with, each of these three cities is the most important economic powerhouse of their home economies, which are of course at different levels of development. As Table 5 shows, both GNI per capita and emissions per capita is highest in Mexico and lowest in India. However, emissions per capita in China are very close to Mexico's, although its GNI per capita is less than one-fourth of Mexico's. This is explained by the differences in their energy systems and economic structures: as Table 6 shows, industry is much more important in China's economy than Mexico's. Furthermore, Table 5 shows that economic growth is much faster in China than in Mexico or India.

TABLE 5
Country Profiles for China, India and Mexico

Indicator	Emissions (metric tons per capita) (2004)	GNI per Capita (Atlas method, US$) (2004)	GDP Annual Growth (%)	
			1990-2000	2000-05
India	1.24	630	4.2	4.7
China	3.86	1500	10.6	9.6
Mexico	4.29	6930	3.1	1.9

Source: World Development Indicators 2007.

Interestingly, measured by absolute fall in manufacturing employment, China started to de-industrialize the earliest in 1992 (partly as a correction of its over-industrialization before the onset of its economic reform), followed by India in 1997 and Mexico in 2000 (Table 6). In terms of industrial value-added as percentage of GDP (a less reliable indicator for industrialization/de-industrialization due to short-term price changes), China and India appear to have followed a trend of industrialization/re-industrialization since 2000, whereas the trend in Mexico is less clear.

TABLE 6
De-industrialization in China, India and Mexico

Manu. Employment (1,000)	Manufacturing Employment (1,000)			Industry Value-Added as % of GDP		
	China	India	Mexico	China	India	Mexico
1990	53040	6118		42	28	28
1991			3628			
1992	55417					
1993			3838			
1995		6767				
1997		7068				
2000	32400	6119	5749	46	26	28
2003			5178			
2005				48	27	26
2007			5449	49	30	36

Source: International Labour Organisation (1998 -2009); World Development Indicators online database.

At the city level, all three cities have de-industrialized, although to different extents and with varying levels of importance for manufacturing (Table 7). Of the three cities, Shanghai is the most industrialized with industrial jobs accounting for 32% of total employment in 2006. Mexico City was the earliest to begin de-industrializing, beginning probably even before 1970, followed by Mumbai (from early 1980s) and finally Shanghai in 1990. Interestingly, these cities have done so for quite different reasons, in addition to normal demand and supply factors. In Mumbai, this was largely due to the effects of the 1981 textile workers strike and the land ceiling policy (Pacione 2006). In the case of Mexico City, the rise of manufacturing along the USA-Mexico border and de-concentration policy played a role (Grajales forthcoming). Finally in the case of Shanghai, the government's prioritization policies as well as surging domestic demand for services are responsible (Zhang 2003).

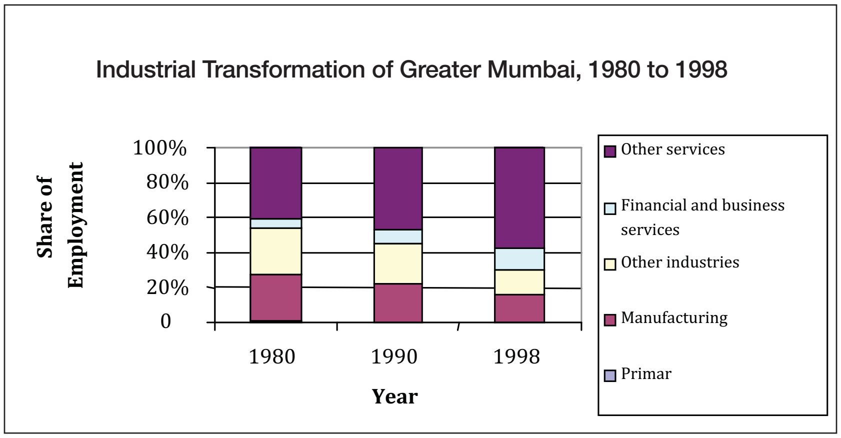
TABLE 7
De-industrialization Trends in Mumbai, Shanghai and Mexico City

	Greater Mumbai (Manufacturing employment as % of total employment)	Shanghai (Industrial employment as % of total employment)	Mexico City Metropolitan Area (Manufacturing share in GDP)
1960			21.26
1970			23.80
1980		42.90	23.78
1985	35.97	44.30	
1988			23.78
1990		53.88	
1993	28.47		18.61
1995		49.96	
1998			19.21
2000	17.84	39.72	
2006		32.13	

Sources: Mumbai Metropolitan Regional Development Authority (2001); Grajales (forthcoming) and Shanghai Statistical Yearbook (various years). Industrial employment for Shanghai covers manufacturing and utilities.

Although the lack of comparable data precludes any attempt to quantify the effect of de-industrialization, it is evident that the three cities perform differently in economic terms. Grajales (forthcoming) notes that from 1980 to 1998, Mexico City Metropolitan Area progressively slid down the national labour productivity league table for metropolitan areas from the 8th place to 19th place. Mumbai's annualized GDP growth rate registered 8.5% from 2001/2 to 2006/7, which is only slightly above the national growth rate of 8% for the same period (The Economic Times, 20 Jan. 2008). Its economic structure, characterized by a small manufacturing sector and a large group of low value-added 'other services', is a likely contributor to this outcome (Figure 3: De-Industrialization in Mumbai). In comparison, Shanghai's GDP grew by 12.5% per annum between 1992 and 2007, compared with 9.4% per annum for the national average (1992-2006). It would seem that economic structure matters here too.

FIGURE 3
De-Industrialization in Mumbai



Source: Mumbai Metropolitan Regional Development Authority 2001.

There is also evidence that industry is not where the greatest mitigation challenge lies. This is clearly illustrated by the experience of Shanghai. While energy consumption has declined significantly in industry, it has risen rapidly in the rest of the economy and in the household sector (by 14.64% between 2005 and 2006 in the latter) (Table 8 and Table 9). Furthermore, while energy intensity is higher in the secondary sector (especially in industry) than elsewhere, it is falling fast, by 6.18% from 2005 to 2006 alone. By contrast, energy intensity is increasing (although only slowly) in the tertiary sector. These mean that the greatest mitigation challenge will be to contain the growth of energy consumption outside industry even in Shanghai, the most industrialized city of the three.

TABLE 8
Allocation of electricity consumption in Shanghai in 1990, 2000 and 2007

Year	Industry (%)	Agriculture (%)	Households (%)	The Rest (%)
1990	83.5	2.7	5.5	8.4
2000	70.3	1.6	9.5	18.6
2007	65.8	0.5	12.2	21.5

Source: Shanghai Statistical Yearbook 2008.

TABLE 9
Unit energy consumption of different economic activities, Shanghai, 2006

Indicators	Unit	Amount	Change Over 2005 (%)
Energy /GDP	TSC/Yuan	8370	-3.71
Energy/value added			
- Primary sector	TSC/Yuan	9840	-7.79
- Secondary	TSC/Yuan	11120	-6.08
Of which: industry	TSC/Yuan	11600	-6.18
- Tertiary	TSC/Yuan	4950	0.13
Household energy consumption	1,000 TSC	7535.1	14.64

Source: Shanghai Statistical Bureau 2006. TSC stands for tons of standard coal.

5. CONCLUSION

This paper has attempted to examine the implication of climate change for economic development strategies for Southern cities, focusing on the question whether climate change makes industrialization an obsolete strategy. Through the lens of Kaya Identity, industrial history, and theories of industrialization and de-industrialization, and considering the development experiences in Shanghai, Mumbai and Mexico City, it demonstrates that this is not so. Indeed, it advances the hypothesis that climate change will make industrialization a more important strategy than ever before. The implications are several-fold. First, addressing climate change does not call for the abandonment of industrialization, or pre-mature de-industrialization. Second, however, industrialization cannot carry on with its present mode of development—industries must be de-carbonized for the sake of local and national long-term prosperity as well as global sustainability. Finally, if the preliminary trend of decreasing energy intensity in Shanghai is any guide, then this can be achieved. Further research is needed, however, to formulate the practical ways forward.

References

Banuri, T., J. Weyant, G. Akuma, A. Najam, L. Pinguelli Rosa, S. Rayner, W. Sachs, R. Sharma, and G. Yohe. 2001. *Setting the stage: Climate change and sustainable development*. Cambridge: Cambridge University Press.

Burton, I., E. Diringer, and J. Smith. 2006. *Adaptation to Climate Change: International Policy Options.* Arlington, USA: Pew Center on Global Climate Change.

Chandler, W., D. Schaeffer, D. Zhou, P. Shukla, F. Tudela, O. Davidson, and S. Alpan-Atamer. 2002. *Climate Change mitigation in developing countries: Brazil, China, India, Mexico, South Africa, and Turkey*. Washington, D.C.: Pew Center on Global Climate Change.

Chenery, H., S. Robinson, and M. Syrquin. 1986. *Industrialization and Growth: A Comparative Study.* New York: Oxford University Press.

Dasgupta, S. and A. Singh. 2006. "Manufacturing, Services and Premature De-industrialization in Developing Countries: A Kaldorian Empirical Analysis." Working Paper 327, Centre for Business Research, University of Cambridge.

Eriksen, S. and K. O'Brien. 2007. "Vulnerability, Poverty and the Need for Sustainable Adaptation Measures." *Climate Policy* 7: 337–52.

Fukunishi, T., M. Murayama, T. Yamagata, and A. Nishiura. 2006. *Industrialization and Poverty Alleviation: Pro-Poor Industrialization Strategies Revisited.* Vienna: United Nations Industrial Development Organization (UNIDO).

Graham, D. and N. Spence. 1995. "Contemporary Deindustrialization and Tertiarisation in the London Economy." *Urban Studies* 32 (6): 885–911.

Grajales, G. Forthcoming. "The Manufacturing-Service Nexus in a De-industrialising City Economy: The Case of Mexico City." Unpublished Doctoral Dissertation, University College London, London.

International Energy Agency (IEA). 2007. *World Energy Outlook 2007.* Paris: OECD / IEA.

International Energy Agency (IEA). 2008. "Chapter 7 - Energy-Related Carbon Dioxide Emissions." In *International Energy Outlook 2008.* Paris: IEA. http://www.eia.doe.gov/oiaf/ieo/emissions.html (accessed Feb 27, 2009)

ILO (International Labour Organisation) 1998-2009. *LABORSTA Labour Statistics Database.* Geneva: ILO. http://laborsta.ilo.org/.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report*. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf. [Accessed March 1, 2009].

Kaldor, N. 1966. *Causes of the Slow Rate of Economic Growth of the United Kingdom.* Cambridge: Cambridge University Press,

Kaldor, N. 1978. *Further Essays on Economic Theory*. New York: Holmes and Meier.

Kuznets, S. 1966. *Modern Economic Growth: Rate, Structure and Spread*. New Haven: Yale University Press.

Lever, W.F. 1991. "Deindustrialization and the Reality of the Post-Industrial City." *Urban Studies* 28 (6): 983–99.

Martinussen, J. 1997. *Society, State and Market: A Guide to Competing Theories of Development*. London and New York: Zed Books.

McCarthy, J. J., Canziani O. F., Leary N. A., Jijjeb D. J., and White K. S. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Cambridge: Cambridge University Press.

Meier, G. M. 1995. *Leading Issues in Economic Development, 6th edition*. New York and Oxford: Oxford University Press.

Mumbai Metropolitan Regional Development Authority. 2001. *Population and Employment Profile of Mumbai Metropolitan Region*. Mumbai Metropolitan Regional Development Authority. http://www.mmrdamumbai.org/. [Accessed March 9, 2009].

Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T. Y. Jung, T. Kram, E. L. La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H. H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, D. Victor, and D. Zhou. 2000. *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Nakicenovic, N., Kolp, P., Riahi, K., Kainuma, M., & Hanaoka, T. 2006, "Assessment of emissions scenarios revisited", *Environmental Economics and Policy Studies*, 7: 137-173.

Pacione, M. 2006. "City Profile: Mumbai." *Cities* 23 (3): 229–38.

Price, L., S. de la Rue du Can, J. Sinton, E. Worrell, N. Zhou, J. Sathaye, and M. Levine. 2006. *Sectoral Trends in Global Energy Use and Greenhouse Gas Emissions*. Energy Analysis Department, Environmental Energy Technologies Division, Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-56144.

Roberts, J. T., and B. C. Parks. 2007. *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy*. Cambridge and London: The MIT Press.

Robins, N., R. Clover, and C. Singh. 2009. *A Climate for Recovery: The Colour of Stimulus goes Green*. London: HSBC Bank plc.

Robins, N. and R. Kumar. 1999. "Producing, Providing, Trading: Manufacturing Industry and Sustainable Cities." *Environment and Urbanization* 11 (2): 75–94.

Rogner, H.-H., D. Zhou, M. Bradley, P. Crabbé, O. Edenhofer, B. Hare, L. Kuijpers, and M. Yamaguchi. 2007. "Introduction." In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. B. Metz and others, 95–116. Cambridge: Cambridge University Press.

Rowthorn, B. and R. Ramaswamy. 1999. "Growth, Trade and Deindustrialization." IMF Staff Papers, 46 (1): 18–41.

Shanghai Statistical Bureau. 2006. *Communique of Energy GDP Unit Consumption Indicators of Shanghai Municipality*. Shanghai: Shanghai Statistical Bureau. http://tjj.sh.gov.cn/2005shtj/xw/node49/userobject1ai2936.html. [Accessed March 1, 2009].

Smit, B., O. Pilifosova, I. Burton, B. Challenger, S. Hug, R. J. T. Klein, and G. Yohe. 2001. "Adaptation to Climate Change in the Context of Sustainable Development and Equity." In *Climate Change 2001: A Contribution of the Second Working Group to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, 797–912. Cambridge: Cambridge University Press.

Syrquin, M. 1988. "Patterns of Structural Change." In *Handbook of Development Economics 1,* ed. H. Chenery and T. N. Srinivasan, 203–73. Netherlands: Elsevier Science Publishers.

Thirlwall, A. P. 2003. *Growth and Development: With Special Reference to Developing Economies. 7th ed.* Basingstoke and New York: Palgrave Macmillan.

UN-HABITAT. 2006. State of the World's Cities 2006/7. Nairobi: UN-HABITAT.

World Bank. 1990. *World Development Report 1990/1991*. Washington, DC: World Bank.

________. 2008. World Development Indicators 2008. Washington, DC: World Bank.

Young, A. A. 1928. "Increasing Returns and Economic Progress." *Economic Journal* 38 (December): 527–42.

Zhang, L.-Y. 2008. *Climate Change and Sustainable Development: Linkages and Approaches for Integration*. A Commissioned Report for DESA, UN.

Zhang, L.-Y. 2003. "Economic Development in Shanghai and the Role of the State." *Urban Studies* 40 (8): 1549–72.

CHAPTER 23

Adaptation and Mitigation: What Financing is Available for Local Government Investments in Developing Countries?

Thierry Paulais,* Juliana Pigey

Summary

This article reviews specific funding available for adaptation and mitigation investments of cities, and discusses the mismatch between needs and financing tools. These funding sources are insufficient, highly fragmented and not really tailored to local governments. They are narrowly sector-based and risk being counterproductive in the urban context. Furthermore, they are complex and costly to access, or else targeted to sovereign borrowers. The article makes proposals to adapt these finance tools, re-introduce local authorities in mechanisms from which they are presently excluded, and create incentives in their favor. Finally, it proposes an initiative for cities in fragile states, based on greater involvement of wealthy Northern cities and the recourse to a specific financing mechanism.

Key Words: Adaptation, Mitigation, Financing, Investments, local governments

*Corresponding author: paulaist@afd.fr

1. INTRODUCTION AND BACKGROUND

The cities eligible for development assistance will be relatively harder hit than others by the direct and indirect impacts of global warming. Across the African continent, the reduction in arable land per capita due to the combined effects of desertification and demographic growth risks triggering unprecedented migratory flows to the cities (Collier et al. 2008). In other parts of the world, such as the Pacific and Indian Ocean regions, rising sea levels and more frequent hurricanes will force people to relocate homes and businesses (Dasgupta et al. 2007). The economic and environmental repercussions of these migrations and displacements, coupled with the inevitable social tensions they bring, will put a strain on local government (African Development Bank 2009).

Unfortunately, these events will affect urban areas already suffering from serious dysfunctions and deficiencies in housing, water and electricity supply, sanitation and drainage, and management and governance. Furthermore, urban economies, particularly large metropolitan areas, with massive levels of energy use (especially for electricity and urban traffic) will ultimately bear the ineluctably increasing cost of fossil fuels as well as the additional cost of alternative energy solutions (IPCC 2007).

Generally speaking, urban governments, which run local public services that emit large quantities of greenhouse gases (waste, transport, etc…) and who are responsible for implementing policies to effectively reduce emissions (standards and incentives for public and residential buildings, urban traffic, urban planning, etc...) will be under greater pressure to carry out mitigation investments (Reid and Satterthwaite 2007).

These countries' local authorities will ultimately have to shoulder a growing share of the responsibilities and of the investment outlays for at least two reasons. First, this is a structural trend, which appears as a corollary of development: local governments carry out a large proportion of public investment in industrialized countries (over 65 percent on average for Europe), but a low proportion in the least developed countries (less than five percent for Africa). Secondly, central government budgets will be required for core government functions (social, justice and security sectors), whose relative costs are rising, in areas where there is a particularly acute need (world food shock, among others) and for national and regional climate change policies and actions.

This observation should have prompted special initiatives to enable local governments to finance mitigation and adaptation investments and actions. Yet the fact of the matter is that this has not happened. On the contrary, current investment financing facilities, which work at national level and/or are difficult to access and unreliable (Anderson and Chandani 2008), have not been designed for local governments at all.

Moreover, instruments strictly intended for climate change investments could rapidly show their limitations in urban areas where there are many, complex sector interdependences (Satterthwaite et al. 2007). More seriously, addressing climate change separately from environmental issues in general, and urban management in particular, could even prove counterproductive.

Perhaps most importantly, the financing currently available via these specialized instruments appears to cover only a minute proportion of the estimated investment needs. Ordinary local investment financing tools need to be mobilized, and they themselves have limited intervention capacities, just as the local authorities' borrowing capacities are limited. In these circumstances, it is vital to seek leverage by mixing different types of resources from diverse sources and to set up incentive policies to encourage local governments to make this type of investment a top priority.

It is in the least developed countries that the situation of cities could turn out to be particularly dramatic. A large number of these countries are in regions where the effects of global warming will be the most severe (Collier and al. 2008; Toulmin 2009); and the local government sector in these countries is often a sparse affair, with few human and financial resources, little borrowing capacity, and limited or no access to the capital markets. If these cities are to effectively — or at least partially — address mitigation and adaptation, specific assistance and financing arrangements will probably have to be found.

This paper develops this argument in five sections. The first section looks at mitigation and adaptation in a general urban context. The second section presents the different financing tools in place and their investment capacities, and discusses whether cities have the possibility of gaining access to them, directly or indirectly via financial intermediaries. The third section looks at different solutions available for channeling financing through local governments, especially for mitigation/adaptation investments. The fourth section looks into solutions that could create leverage for existing financing, and develop incentives for local authorities to invest in adaptation/mitigation even though they have other legitimate priorities. The fifth and last section explores possible ways of providing specific resources and assistance to the cities most in need, such as those in post-conflict countries and fragile states.

2. A VERTICAL, SECTOR-BASED APPROACH IS NOT SUITED TO URBAN CONCERNS

In practice, mitigation and adaptation/ actions can rarely be taken independently of their surrounding environment. Any investment in urban areas interacts with sectors other than that in which the investment is made, and therefore needs to be part of an integrated approach (this is even the case of the seemingly most straightforward actions, for example, replacing high-energy emitting light bulbs with low-energy light bulbs in street lamps, since it is necessary to develop specific collection systems for the used bulbs.). In most cases, climate change investments overlap with environmental and urban policy issues, and with the city's economic and social life. This can be seen from the following examples.

2.1 Adaptation

Protecting coastal cities from rising sea levels cannot be addressed without considering drainage and sanitation, as well as soil use. In Algiers, the Bab el Oued flood disaster in 2001 (800 dead) was caused by a downstream malfunctioning drainage channel that due to the rise in the sea level (because of the combined high tide and high winds) no longer drained. Yet upstream, there was an unprecedented volume of water to be drained due to the torrential rainfall, as well as poor maintenance of the drainage system and, most importantly, soil erosion in the city heights caused by uncontrolled deforestation and urbanization. In Lomé, where part of the city centre is at sea level and rainwater has to be drained by lift stations, it is vital to protect the offshore seawall and keep the drainage channels in working order. Yet the lagoon, which serves as a flood control reservoir, and the lift stations cannot keep pace with the increase in water volumes prompted by soil erosion because of the expansion of informal urbanization in the city's heights.

2.2 Mitigation

In the transport sector, exclusive lanes and ways for buses and trams are seen as one of the best means of reducing greenhouse gas emissions. This is surely the case, to the extent that potential negative externalities of such investments – induced alternate traffic patterns, increased urban spacing – are identified and addressed at the same time. And, in a city where the informal sector provides transport services, setting up a formal public transport system means that the entire transportation supply has to be re-considered. At the same time, this system could have negative effects on local finances due to escalating operating costs, and a negative impact on employment if the changes in the informal sector are not carefully managed and assisted.

In the waste disposal sector, methane capture in solid waste landfills is a relatively easy mitigation action (Dessus and Laponche 2008). Yet from the urban manager's point of view, the fact that the landfill can be partially financed by carbon funds is not enough to make it a good investment. The local authority's investment is justified for environmental reasons in the broad sense; and a landfill is only worth the sum total of the parts of the waste disposal sector (collection, intermediate storage and transport). Given that this sector is generally the largest item of operating expenditures, any investment decision could weigh on the local government budget balances for years to come.

In these examples, a strictly technical "climate change" approach to the situation is not sufficient to solve the problem and can even lead to negative indirect effects for a city. For instance, applications for carbon fund financing have been made by solid waste landfill operators who are ostensibly the sole beneficiaries, without any mention of the existence and costs of running the upstream branch that supplies the site. The sector-based approach — and even a sub-sector approach in the present case if one considers that climate change is part of the environmental agenda — and vertical funding are not well suited to projects in urban areas, which, by their very nature, call for a transversal and territorial approach.

3. FINANCING FALLS FAR SHORT OF NEEDS AND IS NOT SUITED TO LOCAL GOVERNMENT

There are two main types of funding: the mechanisms based on market financing (carbon finance, in particular) and the funds that provide subsidies and concessional finance. Table 1: Funding Sources for Mitigation, and Table 2: Funding Sources for Adaptation present a summary and description of these subsidy and concessional funding mechanisms and their respective goals. What is immediately striking is the complexity of the institutional landscape: such fragmentation must surely undermine the effectiveness of the whole. It adds to the opaqueness of a set-up that no one can easily see as coherent, so much so that, in some countries, the donors themselves have decided to set up bodies to group and coordinate the financial flows and actions of these different instruments (Ayers 2009).

The majority of these funds concern intangible actions (studies, training, planning, action plans, research and development, pilot initiatives, etc.). Among these are the National Adaptation Plans of Action (NAPA), which define investment programs for urgent adaptation needs. Yet the financing capacities of these funds are only capable of covering a small fraction of investments needs. And needs estimates are highly approximate. In mitigation, the hypotheses considered for emissions reduction levels and the largest emitters' efforts set annual investment needs for the developing countries at anywhere between US$80 billion and US$500 billion (World Bank, 2008). In adaptation, the different sources and methods estimate needs somewhere between US$10 billion and US$90 billion per year (Oxfam 2007).

Carbon finance, notably through the Clean Development Mechanism, is to-date the most important source of mitigation financing for developing countries. The total amount of funding which can be expected is based on various estimates, due to the fact that they are based on hypotheses for future carbon prices. It should be noted that a number of experts consider these

TABLE 1
Funding Sources for Mitigation

Financing Instrument	Managed by	Amount	Nature of Support	Purpose	Beneficiaries – Status – Urban Finance friendly?
UNFCC and Kyoto Protocol Instruments					
Global Environment Facility	GEF	Target: USD $1 bn. Commited: $352 mn.	Project	GEF Trust Funds allocated to pilot adaptation activities in developing countries (project support)	Eligible project must generate "global environmental benefits"
Clean Development Mechanism	GEF	USD $15 - $25 bn	Project	Carbon emissions reduction (CER) credits market	High transaction costs and high level of knowledge required to justify projects, as well as up-front investment costs
Multilateral Development Bank Instruments					
Clean Technology Fund (CTF)	World Bank	USD $ 4.3 bn	Project	Promote scaled-up demonstration, deployment & transfer of low-carbon technologies for power sector, transportation, and energy efficiency in buildings, industry & agriculture.	Potential opportunity for urban municipalities to participate in joint exercise to discuss with government, industry, and other stakeholders to develop a country-led investment plan. Mostly targeted at sovereign and private sectors
Strategic Climate Fund (SCF) – Scaling-up renewable energy		USD $70 mn			
Bilateral Instruments					
Cool Earth Partnership	Japan	USD 8,000 mn		Assistance for improved access to clean energy	
German International Climate Initiative (GICI)	Germany	USD $40-$80 mn/year		Sustainable energy projects / Funded by auctioning up to 10% of Germany's allowances from EU ETS (2008-2012)	
Environmental Transformation Fund - International	United Kingdom	USD $1.6 bn over 3 years from 2008		Support to programs and projects to address climate change	

TABLE 2
Funding Sources for Adaptation

Financing Instrument	Managed by	Amount	Nature of Support	Purpose	Beneficiaries - Status - Urban Finance Aware?
UNFCC AND KYOTO PROTOCAL INSTRUMENTS					
Strategic Priority on Adaptation – SPA (2003)	GEF	USD $50 million Allocated for 22 projects	Project	GEF Trust Funds allocated to pilot adaptation activities in developing countries (Project support)	Not clear how/if urban municipalities can access. Eligible project must generate "global environmental benefits" / incremental costs linked with increasing resilience funded by SPA
Special Climate Change Fund (SCCF)	GEF	USD $90.3 million Total / USD $67.5 million allocated to 15 projects	Project	Finance adaptation activities related to climate change complementary to those funded by GEF Trust Fund	Not clear how/if urban municipalities can access. Climate change affects core development sector: agriculture-water-health-infrastructure / Finances additional costs of adaptation
Least Developed Countries Fund (LDCF)	GEF	USD $172 million	Project	Finance preparation & implementation of NAPAs to address urgent/immediate adaptation needs of LDC Parties; 38 NAPAs completed; 24 submitted projects to GEF for approval; 19 approved (as of 21-Oct-08)	Depends on how country involves urban municipalities in preparation of NAPAs. Climate change affecting core development sector: agriculture-water-health-infrastructure / Finances additional costs of adaptation
Adaptation Fund	Adaptation Fund Board / GEF is Secretariat / WB is Trustee	USD $400-1500 millionn / of which about USD 91 millionn available	Programmatic	Funded from 2% levy on transactions under the CDM; to finance adaptation programs/ projects in developing countries party to Kyoto Protocol	Countries are beneficiaries / can designate implementation agents, eventually urban munis? Principles: Funding on full adaptation cost basis; short projects development-approval cycles; country-driven projects

TABLE 2, *continued*

MULTILATERAL DEVELOPMENT BANK (MDB) INSTRUMENTS					
Strategic Climate Fund (SCF) : Pilot Program for Climate Resilience (PPCR)	World Bank	Target USD $1 billion / Available USD $240 million	Budget / SWAPs / Coordinated investment programs	Grant & concessional finance to 5-10 countries to integrate climate resilience with development planning & poverty reduction strategies and fund investments identified in the plans. Mobilizes new/additional funding	Urban issues not directly addressed but potential of link to urban issues in the planning. Access via MDBs, so via sovereign
Global Facility for Disaster Reduction and Recovery (GFDRR)	World Bank			Technical/financial assistance to mainstream disaster reduction in national development strategies/plans	Urban areas are at high risk, depend on involvement of urban sector in strategy preparation. High risk low & middle income countries
BILATERAL INSTRUMENTS					
Cool Earth Partnership	Japan	USD $2,000 millionn		Assistance in adaptation to climate change / improved access to clean energy	
Global Climate Change Alliance (GCCA)	European Commission	USD $84 million		Draws on EU ETS proceeds to help most climate change vulnerable developing countries (LDCs / SIDS)	
German International Climate Initiative (GICI)	Germany	up to USD $40 million/ year		Support adaptation / Funded by auctioning about 10% of Germany's allowances from EU ETS (2008-2012)	
UNDP-Spain Millennium Development Goals Achievement Fund	UNDP-Spain	USD $22 million		Interventions to improve environmental management / service delivery at local / national levels; efforts to enhance adaptive capacity	

forecasts to be overestimates, as they take into consideration the volume of carbon market transactions—markets in which the same credit is sold twice, on average, and thus double-counted. For example, the CDM is expected to have provided US$15 billion to US$25 billion in direct resources by 2012 and the end of the Kyoto Protocol; these are hypothetical amounts, which will ultimately be compared to the effective payments (United Nations — UNFCCC 2008). The other important imminent source of funding comes in the form of the Climate Investment Funds (CIFs), made up of the Strategic Climate Fund (SCF) and the Clean Technology Fund (CTF). The SCF also targets mainly mitigation, via a forest program and a renewable energy program. A small share of the SCF (US$ 240 million) is earmarked for pilot adaptation operations. The CTF has an allocation of over US$4.3 billion and will provide concessional financing for low-carbon investment in the energy and transport sectors, and energy efficiency in building, industry and agriculture (World Bank 2008).

Carbon finance provides, in principle, financing which is additional to traditional Official Development Assistance (ODA) (Oxfam 2008). However, in practice, it appears that the subsidy provided by CDM is, in part, pushing aside traditional ODA and leads, therefore, to a substitution effect rather than an additional effect. Furthermore, a review of approved CDM operations indicates a strong geographical concentration on a small group of countries (China, India, Brazil), as well as sectoral concentration (almost half of financial volumes are related to hydrofluorocarbon gas from the chemical industry) (Pfeifer and Stiles, 2008, World Bank, 2006). This reveals methodological problems (only effectively measurable emissions reductions are financed), which are at the present time difficult to avoid, and can be considered a result of the vertical nature of this financing mechanism.

Adaptation funding is set to benefit from the gradual operationalization of the *Adaptation Fund*, created in late 2007 and due to be financed by a two percent tax on CDM transactions. This fund could free up between US$400 million and US$1.5 billion by 2012, depending on carbon prices.

It is hard to estimate what share of these investments the private sector might pick up. Yet no matter what, investment needs are expressed in billions whereas the unit of account for each of these funds is in the tens of millions, or at best hundreds of millions. That gives an idea of the extent of the funding shortfall.

In addition to this lack of financing, local authorities also face a problem with the characteristics and even accessibility of the available financing.

On the one hand, a market mechanism like the CDM theoretically lends itself well to local urban financing under the management of a local authority or one of its divisions — such as a local utility — or a private partner in the case of a service concession. Urban projects which receive the most benefit from this type of financing include essentially the waste sector, public street lighting and transport.

At present, however, public transport projects are difficult to fund with carbon finance mechanisms due to the methodological issues for the measurement of emissions reductions, as mentioned above. Carbon finance provides additional funding that could prove decisive to include an investment in a city's program that might otherwise have been excluded.

From the perspective of local governments, effective recourse to CDM is stymied by a certain number of constraints and limitations. Firstly, the uncertainties currently surrounding the market's continuity after 2012 are hardly likely to set investors' minds at rest, even if some funds are committed to purchase contracts beyond this date (Figueres and Newcombe 2007). Then there is the fact that this instrument is complicated to use, demands know-how beyond that of most people, and calls for sophisticated appraisals that can prove extremely expensive when compared with the resources obtained. These resources moreover have the disadvantage of being quite uncertain, given the volatility of the market and the time it takes to register the project and then establish the volumes the project will earn in reality; it is essential to not draw up a financing plan on the basis of over-optimistic assumptions. Last but not least, even if carbon finance provides revenues *ex post*, it has difficulty addressing the question of initial financing. Some funds can make advances of up to 20 or 25 percent of the amount of a purchase contract, but this requires a guarantee. The future revenues of an *Emission Reduction Purchase Agreement* (ERPA) can theoretically be backed by up-front financing, but such a structure obviously adds cost and increases the complexity of the operation.

The indirect effect of these constraints and uncertainties is to make carbon finance a tool better suited to large-scale projects, for which appraisal costs can be recouped, in a sector for which a simple and reasonably precise measurement approach exists and, for which financing is available.

For example, we can cite the project for the controlled landfill for Greater Amman, which simultaneously obtained a World Bank loan and an ERPA. The World Bank loan is for USD $18 million to the municipality, but with State guarantee. The ERPA of the Carbon Fund for Europe amounts to 900,000 tons of CO2-equivalent from now through the end of 2014. Captured methane will be used for electricity generation. We know that the profitability of these projects will be improved a posteriori by the revenues, but in varying proportions that are problematic to determine precisely in advance: many parameters come into play such as the volume of waste, its composition and the climate. There is a floor below which projects do not provide a sufficient return to be eligible for carbon finance. For large projects, the additional revenues can account for 15 to 50 percent of the investment (and up to 75-80 percent in the case where revenues can be earned from sales of generated electricity and if it can be sold at high prices). A city seeking to finance several projects has to wade through the same appraisal and registration procedure for each project, with the same uncertainties every time.

The day the uncertainties about the future of carbon finance are lifted, the mechanisms that currently govern its implementation will have to be revised. It would be wise for carbon finance to move towards holistic urban approaches: i.e. to finance programs of operations based on overall performance. To meet this objective, methodologies to consolidate/improve emissions reductions measurements in the sectors of waste, energy and transport are currently being developed. Furthermore, it is likely that if the donors set up simple and inexpensive up-front financing arrangements on the strength of pledges based on future revenues from purchase contracts (eventually incorporating a guarantee to cover possible revenue fluctuations, within agreed upper and lower limits), this could have a significant mobilizing effect.

On the other hand, a tool such as the CTF has a precise global instrumental purpose: to reduce greenhouse gas emissions. It has huge sums of financing to allocate, and consequently disbursement challenges to meet. Yet the CTF takes a wholesale approach: the targeted investments are large (electricity generation, for example) and the recipients are explicitly central government, that is, "sovereign" borrowers. These borrowers could admittedly onlend these loans to local governments, but the existence of a threshold for fund eligibility (given as an investment amount) makes this prospect unlikely. For example, if the CTF looks into the possibility of financing investments in public transport for a local authority, it would only be with central government's approval, under its guarantee and within a national program concerning a number of sites (World Bank 2008).

Local urban authorities are clearly absent from the CTF's operational strategies. This could be due to the nature and volume of the investments targeted, but it is also most likely due to the more prosaic reason that most of the multilateral donors can only lend to central governments or with the central government's guarantee (termed "sovereign" loans). Although initiatives have recently been taken to enable these donors to work with what is known as the sub-sovereign market, these commitment volumes are still relatively low (for example in the World Bank-IFC Subnational Program portfolio). There is still a reluctance from most of the multilaterals to deal directly with these borrowers. It is significant that local government is absent from the CTF's stakeholders, given that these stakeholders cover a good dozen types of players: private sector bodies, scientific and technical experts, civil society representatives, indigenous peoples' representatives, etc.

4. CHANNELING FINANCING TO LOCAL URBAN AUTHORITIES

There are two main cases: countries with financial intermediation tools for local government, and those without.

4.1 Where a National Intermediation Tool Exists

A financial intermediation agent (municipal development fund type) can act as a wholesaler to obtain foreign financing for a group of municipalities from the CTF or other sources (with a central government guarantee, if necessary). This technique of grouping together borrowers is also used to give small and medium-sized local authorities access to good financing conditions on the capital markets. In countries where financing can be found on the markets, this gives them the opportunity to secure financing in local currency. Once the financing is secured, the intermediary redistributes it on a retail basis in keeping with the disbursement needs for the cities' respective projects (and consequently also plays a cash flow role).

The intermediation agent can also play a simple supporting role in implementation. Such is the role, for example, of Morocco's municipal fund, the *Fonds d'Equipement Communal* (FEC) in the loan that the World Bank granted to the central government for a national solid waste program. Under this program, the government has tasked the FEC with helping the municipalities and operators to put together program dossiers and negotiate them with the CDM. The additional resources obtained from carbon finance would be shared between the local authorities and the operators. Under the agreed arrangements, the operators finance the investments and pass these costs on in the form of fees. The local authorities should be able to use carbon finance to reduce the impact of these fees on their operating budgets, although the bulk of these budgets remain covered by central government allocations.

4.2 Where No National Intermediation Tool Exists

Some large cities in emerging countries have set up local investment funds to access loans or the capital markets. In the People's Republic of China, for example, where the local authorities are not authorized to borrow, the government arranged for special bodies to be created in the late 1990s. The local authorities own *Urban Development and Investment Corporations* (UDIC), in which they hold assets and liabilities. UDICs are used to finance infrastructure projects, mainly by means of bank loans, public-private partnerships (such as concessions and build, operate, transfer [BOT] arrangements), as well as property development (e.g. building leases, etc…). They delegate the developer for new investments and supervise the management of existing investments.

Vietnam has set up similar bodies in the form of local development investment funds (LDIF), the largest of which to date is the *Ho Chi Minh City Investment Fund* (HIFU). The main difference between these funds and the Chinese model is that they are financial institutions whose role is to collect medium- and long-term resources, take direct holdings in projects, and take shares in construction and civil engineering companies. These funds can issue bonds, provided they are authorized to do so by the local authority.

These two types of local institutions are examples of structures that can receive funds from the CTF or other sources (and possibly hybridize them, see following section) and implement the adaptation and mitigation investments at a rational territorial level (World Bank 2008).

In small countries where there is no reason to set up such local and national bodies, funds for local government investments can be transited through the retail banks. It is widespread practice for donors to grant credit lines to banks and to distribute retail subsidized financing to private-sector companies to meet environmental standards. The same principle could well be applied to local authorities. Cities in Cape Verde, for example, have access to financing for their investments from the retail banks, which are refinanced by a donor (in this case the French Development Agency). A project assistance and preparation unit has been set up by the national association of municipalities (*Associaçao Nacional dos Municipios Cabo-verdiano*) to manage and stabilize the system.

5. HOW TO CREATE LEVERAGE AND INCENTIVES FOR LOCAL GOVERNMENT

Finding sources of leverage is vital given the huge gap between adaptation and mitigation investment needs and currently available funding capacities. As we have seen, in the urban environment, it is difficult in practice to distinguish between climate change investment and pure development investment. One way of facilitating the implementation of dovetailed strategies would be to effectively consolidate these two sources of financing.

Yet in addition to the availability of financing, the question of incentives is also crucial to the least developed countries' cities. These cities are confronted with both a surfeit of needs, some of which are vital, and a shortage if not a complete lack of resources for investment (Reid and Satterthwaite 2007). For these cities, the cost of not taking mitigation action is zero and investment in adaptation is second or third on the list of priorities.

Incentives can come from the governments, mainly in the form of additional allocations from the central government budget for investments to meet a given mitigation or adaptation goal. Incentives can also take the form of tax provisions, interest rate subsidies and even the transformation of loans into grants, contingent upon achieving predetermined goals, obviously provided that the funds for such mechanisms are made secure in the aid systems.

Examples of the different leverage and incentive techniques and measures are the hybrid loan, credit enhancement, the buydown loan, whose characteristics change depending on output, and obviously the various tax incentives for the private sector as either investor or operator.

The *hybrid loan* is the result of a subsidy injected into a financial product (if this product is already subsidized, the new contribution acts like an increase in the grant element) to reduce its rate or change its characteristics (length and/or grace period) to adjust it to the nature of the investment. The hybridization can be perpetuated by the creation of a *revolving fund* (a model that can combine tax incentive provisions). Such a mechanism could be used for local authorities, but also private operators. For example, the United States introduced this model in the 1980s, using subsidies granted by the federal Environmental Protection Agency. Different states set up *State Revolving Funds*, within which these subsidies are hybridized with market resources to create subsidized loans for authorities undertaking a certain type of investment. The reimbursements of these loans replenish the fund, which is also regularly topped up by federal subsidies. The system has since been extended to the drinking water sector, involving private-sector players. Revolving funds have been used for larger scale leverage operations, for example by setting up guarantee funds to improve the retail banks' financing conditions.

Some projects in the transport sector use similar set-ups, such as the Dakar "cars rapides" bus project and the Cotonou motorcycle taxis project (projects financed respectively by the World Bank and the French Development Agency). The idea is to foster the renewal of the stock of passenger vehicles by encouraging (private) owners to buy new, cleaner vehicles that emit less greenhouse gases. These projects use a fund designed to subsidize the scrapping of obsolete vehicles and a bonus paid to buy a clean car. They are underpinned by microcredit and mesocredit establishments that can lend to operators, possibly grouped into cooperatives to stand surety. These operations benefit from tax measures applied to the private sector, whether central government measures (reduced VAT or customs duties on certain types of vehicles) or measures implemented by the local authorities themselves (total or partial exemption from operating fees for a certain length of time, for example).

The *buydown* is a hybrid loan model that incorporates the principles of output-based aid, whereby the loan interest is reduced or cancelled and the loan can be totally or partially transformed into a grant on the basis of actual project or program achievement of measurable targets set in advance. If performance is below par, the loan is not adjusted. Such a mechanism is ideal for a very soft loan with a grace period. The grace period means that output can be assessed before the loan enters the capital reimbursement phase. This type of financial product plays both an incentive and empowerment role. What comes into play is not the availability of the financing, but the price beneficiaries will ultimately pay for it, and, consequently, their capacity to launch further operations with the same budget constraints.

Credit enhancement: donors or specialized institutions provide partial guarantees destined to meet specific objectives for loans provided or bonds issued by financial operators. The guarantee improves the operator's rating and enables him to access resources at better conditions, which he in turn passes on to the borrowers. This solution is used for local authorities that undertake a certain type of operation and for microcredit institutions, which increasingly use the capital markets for their financing. Examples are the lines of credit designed to provide attractive rates for households and small businesses in the informal sector to finance the purchase of solar panels, energy-saving equipment, etc.

These types of incentives therefore call for special financing arrangements upstream of and/or alongside existing funds. In some of the least developed countries, donors have set up decentralization support instruments. These are funds (such as the Agence Nationale d'Investissement des Collectivités Territoriales in Mali, or the Commune/Sangkat Fund in Cambodia) that supplement the central government allocations to the municipalities with subsidies, and are generally the receptacle for the budgetary aid put in place by donor pooling. They finance operating expenditure in certain sectors (especially the social sector) and investment expenditure. These systems could be used to set up incentive instruments, but they focus mainly on small urban authorities and local rural authorities, and their impact on investment is limited insofar as they generally do not have the possibility to lend.

Intermediation tools such as national development funds and special local entities modeled on the UDICs or the HIFU/LDIFs lend themselves well to leverage and/or incentive arrangements of the buy-down type. Such structures are able to both provide advice to the local authorities — which remains a priority goal given the limited absorption capacities — and put together packages featuring this type of financial product.

To increase these intermediation tools' financial resources, their financing would have to be diversified and linked or even mixed using various mechanisms. The development funds are traditionally funded by central government budgets and also by the donors, in the form of concessional loans (generally in foreign currency) or subsidies, depending on the case. Yet, as we have seen, some of these funds have started to finance themselves directly on the financial markets and in local currency.

One of the objectives of these structures, depending on the size and depth of the market in which they operate, should be to position themselves as a credible alternative to national and regional institutional investors, and even sovereign funds, and to attract local savings. Another of their objectives should be to capture the potential new generation resources whose appearance has drastically changed the international aid architecture: carbon finance, obviously, but also remittances (which represent more than international aid in volume terms for some countries) and grants from major foundations (some of which now post much greater intervention capacities than many bilateral agencies). The foundations may be more inclined than the cooperation agencies to make use of the leverage inherent in the above-reviewed incentive models, provided investments are targeted in their areas of intervention and funding traceability is guaranteed.

Upstream, at the level of international aid mechanisms, the search for new resources to fill the current shortfall in financing capacity for climate change investments has become a priority issue. A certain number of proposals have been made by different countries and institutions in order to meet this need. These proposals are not covered here, since they are beyond the scope of this article (for an overview of these proposals, see Müller 2008). The following section looks at a type of initiative that could facilitate priority investments in cities in the least developed countries, post-conflict countries and fragile states.

6. TOWARDS A SPECIAL INITIATIVE FOR CITIES IN FRAGILE STATES OR "TRAPPED CITIES"

Cities in post-conflict countries and fragile states amass handicaps. Their basic investment needs are huge, their implementation capacities are low, and solvency and access to borrowing are minimal or nonexistent. Management and governance problems aggravate their lack of appeal to private investors, and, to a certain extent, donors as well. Moreover, donors, like the states, face pressing needs in areas such as healthcare and food security. So many cities, mainly in Africa, see their economic, financial, social and environmental situation deteriorate from year to year (this, it must be said, in a climate of widespread indifference). They spiral downwards in all areas, sucked into poverty traps —hence the term "trapped cities" — from which it is virtually impossible to escape without outside help (Paulais 2006).

This help does not necessarily imply massive investment sums to begin with, since absorption capacities are relatively low. Yet setting recovery in motion does call for emergency programs in infrastructures and basic services. This means that resources have to be available, not necessarily to finance these programs directly, but to facilitate their implementation. It also means securing a long-term undertaking from committed foreign partners to give the management authorities the wherewithal to gradually develop their capabilities.

Urban sector assistance has not developed many financial engineering or policy innovations in recent years. The healthcare sector has seen the appearance of a new tool, the GAVI Alliance, whose financing is underpinned mainly by borrowing on the markets on the basis of advance pledges from donors. This means that urgent actions way beyond current financing capacities can be taken (HM Treasury-DFID 2003).The GAVI Alliance is a public-private partnership specialized in vaccination campaigns. Its members are made up of donor states, vaccine industry firms, research institutes, UN agencies, international donors and the Gates Foundation (which donated the initial grant). One of the Alliance bodies, the International Finance Facility for Immunization (IFFIm), raises funds for the programs by issuing bonds on the capital markets. These bonds are guaranteed by binding 10-year to 20-year commitments by the donor states. Consequently, they are given a AAA rating by the rating agencies. The Alliance's funds, including funds collected on the markets, are passed on as subsidies to the recipient countries, but these countries must co-finance the programs that concern them. The GAVI Alliance is an innovation in the international aid landscape: an eclectic partnership that has created a simple mechanism, financed by leverage on the capital markets.

This set-up takes advantage of rallying power of the vaccination cause on the international scene. Although mitigation/adaptation for poor cities is probably less gratifying in terms of image, the possibility of creating a similar initiative for trapped cities is worth discussing.

This initiative would be a public-private partnership setup with market service firms (groups working in water, electricity, solid waste and the environment, transport, etc.), donors, regional development banks, major foundations (some of which are already involved in the urban sector, such as the Gates Foundation), sovereign states and rich Northern cities (individually or through their associations). The African continent's sovereign funds might be interested in joining this initiative, which, after all, concerns primarily the African economies and their productivity. Given that these funds - Nigeria, Botswana, Libya, Algeria, Sao-Tomé and Principe, Sudan- represent a cumulative capital of some US$120 billion (African Development Bank 2009), the allocation of just a fraction of their annual earnings would already be significant.

The role of the Northern cities in this partnership would concern institution building, where they have a legitimate part to play, in keeping with multiannual commitments. Yet there is the question of their involvement beyond this type of action: given that the wealth of large cities in the North is comparable with, if not greater than, many sovereign states (the metropolitan areas of Paris and London each account for a GDP amount much greater than those of Belgium or of Sweden, for example), there is good reason to ask whether their solidarity is not financially undersized. These cities have the economic clout and credit quality to mobilize funds, namely by making commitments against guarantees and with ad-hoc revenues from paid services (for example, a recent law in France authorizes local authorities to add surcharges to water rates to finance international solidarity projects in the same water sector; another law authorizes them to sign multi-year cooperation agreements with Southern cities). In addition, the weakness of the institutionalized relations between these associations of cities, donors and major foundations suggests that many opportunities remain to be explored.

The idea of this initiative would *not* be to pass on all of its funds to the recipient cities in the form of subsidies. This approach would deplete investment resources prematurely. The initiative itself should seek leverage at the local level using the above-described mechanisms, with one of its goals being precisely to promote systems in which strengthened local authorities manage to secure local resources for themselves.

The global financial crisis has affected the investment sector as a whole, and a large number of PPP projects in developing countries have been cancelled or postponed (Harris and Pratan 2009; Leigland and Russell 2009). An initiative to help trapped cities with a partnership that collects part of its resources on the markets and from private partners or local authorities in the North, when they themselves have suffered drops in revenues, might be met with a certain amount of skepticism. However, we would point out that the World Bank's first issue of Green Bonds on the Swedish market in 2009 aroused a great deal of interest and raised US$350 million. A second issue in Japan was also a clear-cut success. With the crisis raging, investors have shown interest in AAA-rated products, which meet ethical and environmental concerns about climate change. This gives a glimpse of a potential future with new forms of partnership such as the partnership mentioned for the poorest cities. The financing of mitigation/adaptation investments of trapped cities could become a rallying point.

In the end, this proposal to launch an initiative to support cities in post-conflict and fragile states, leads us back to a general conclusion: the access of local governments to available financing is limited by both the complexity and the fragmentation of these mechanisms. Furthermore, the increasing role of cities in the implementation of urban investments is still largely underrated by the international development and scientific communities. Compounded by the lack of specific urban financing mechanisms, there is considerable risk that the effectiveness of mitigation and adaptation measures in cities will be significantly compromised.

References

African Development Bank and African Development Fund. 2009. *Impact of the Global Financial and Economic Crisis on Africa*. Tunis: ADB

Ayers, Jessica. 2009. "International Funding to Support Urban Adaptation to Climate Change." *Environment & Urbanization* IIED 21 (1): 225–40.

Collier, Paul, Gordon Conway, and Tony Venables. 2008. "Climate Change in Africa." *Oxford Review of Economic Policy* 24 (2): 337–53.

Dasgupta, Susmita, Benoit Laplante, Craig Meisner, David Wheeler, and Jianping Yan. 2007. "The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis". Policy Research Working Paper 4136, World Bank, Washington, DC.

Dessus, Benjamin, and Bernard Laponche. 2008. *Réduire le méthane : l'autre défi du changement climatique.* AFD Working Paper 68. AFD, Paris.

Figueres, Christiana, and Ken Newcombe. 2007. "Evolution of the CDM: Toward 2012 and Beyond." http://www.globalclimateaction.com.

Harris, Clive, and Kumar V. Pratan. 2009. "What Drives Private Sector Exit from Infrastructure? Economic Crises and Other Factors in the Cancellation of Private Infrastructure Projects in Developing Countries." Grid Lines 46, PPIAF, Washington D.C.

HM Treasury. 2003. "The International Finance Facility". *Journal of International Development* 16: 6

IPCC (Intergovernmental Panel on Climate Change). 2007. "Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva.

Leigland, James, and Henry Russel. 2009. "Another Lost Decade? Effects of the Financial Crisis On Project Finance For Infrastructure." Grid Lines 48, PPIAF, Washington D.C.

Müller Benito. 2008. *International Adaptation Finance: The Need for an Innovative and Strategic Approach*. Oxford Institute for Energy Studies, EV 42.

Oxfam International. 2007. Financing Adaptation: Why the UN's Bali Climate Conference must Mandate the Search for New Funds." Oxfam Briefing Note.

Paulais, Thierry. 2006. *Le financement du développement urbain dans les pays émergents : des besoins et des paradoxes*. Revue d'Economie Financière 86. Paris

Pfeifer, Gregor, and Geoff Stiles. 2008. "Carbon Finance in Africa." Policy Paper presented at the "Africa Partnership Forum," Addis Ababa, November 17-18.

Reid, Hannah, and David Satterthwaite. 2007. "Climate Change And Cities: Why Urban Agendas are Central to Adaptation and Mitigation." IIED Sustainable Development Opinion, December 2007.

Satterthwaite, David, Saleemul Huq, Mark Pelling, Hannah Reid, and Patricia Romero Lankao. 2007. *Adapting to Climate Change in Urban Areas. The possibilities and constraints in low- and middle-income nations*. London : IIED.

Toulmin, Camilla. 2009. *Climate Change in Africa*. London: Zebra.

UNFCCC (United Nations Framework Convention on Climate Change). 2008. *Investment and Financial Flows to Address Climate Change: An Update*. Bonn, Germany.

World Bank. 2006. *State and Trend of the Carbon Market 2006. A Focus on Africa*. Washington, DC: World Bank.

_____. 2008. *The Clean Technology Fund*. Washington, DC: World Bank.

CHAPTER 24

High Cost Carbon and Local Government Finance

Patricia Clarke Annez,* Thomas Zuelgaray

Abstract

Global climate change has certain unique features in terms of optimal policy. Some of these have been discussed already at the global level and some at the national level. But what is the impact of these features on local government finance? This paper examines the impact of high cost carbon on municipalities' finance. We compare municipalities finance in India (State of Maharashtra) and in Spain. We conclude that raising energy prices will create an adverse fiscal shock for local governments, the magnitude of which will depend on the structure of spending. Smaller, less diversified governments currently operating at a low level of service and with a very small operating deficit will be harder hit, precisely because the most basic services tend to be energy intensive, and their energy bill is high in relation to their scope for borrowing to weather the shock. However, all municipalities would appear to be hard hit and a system of compensation from national government would be needed to avoid disruption to essential services.

*Corresponding author: pcannez.clarke.work@gmail.com

1. INTRODUCTION

Global climate change has certain unique features in terms of optimal policy. Some of these have been discussed already at the global level and some at the national level. This paper contends that these features will also have implications for fiscal federalism and this area has yet to be given much consideration. Cities, in particular, need to consider the following points.

1. Climate change is a global externality. Accordingly, any reduction in carbon emissions[1] has equal value for mitigating climate change—no matter where the reduction takes place.
2. This implies that the optimal Pigovian tax for reducing carbon emissions is **the same** worldwide, and a fortiori, nationwide. In this way, the cost of reducing global emissions will be minimized because all potential emitters face the same incentive to reduce emissions and will thus face price signals to reduce emissions at least cost first.[2]
3. Partitioning the world into different groups who must reduce emissions looking only at their opportunity set rather than the worldwide set of opportunities for least cost emissions reductions will increase the world wide cost of mitigation. Thus, any policy for mitigation should seek to adhere as closely as possible to the principle of a uniform carbon price. Otherwise the efficiency cost of a major reduction of a critical input economy-wide will be increased, and this is neither desirable nor necessary.
4. This does not imply that all emitters should bear equally all the economic and financial costs of reducing emissions. An equitable policy response requires separating these two aspects of policy formulation. It is quite likely to be the case that considerable negotiations will be needed to create a credible system for burden sharing that will compensate poor countries for the costs they must bear to address a problem that is not of their making because their contributions to the existing greenhouse gas (GHG) stocks are minimal. Even future emissions will not materially change this calculus when considered on a per capita basis.
5. Nonetheless, the long term strategy should to move at a suitable pace toward uniform pricing of the marginal GHG emission. This implies that the costs of energy will have to increase in developing countries.

---

[1]Following common practice, we refer to all greenhouse gas (GHG) emissions as carbon. This is merely a shorthand for purposes of simplicity. Optimal policies will have to distinguish between GHGs based on their different forcing factors (effect on climate). Abstracting from certain scientific uncertainties, these are relatively easily reduced to broadly accepted carbon equivalence factors.

[2]For purposes of simplicity, we ignore questions of phasing here. It may well be politically impossible to raise carbon prices equally worldwide in the immediate or even medium term.

6. Whether or not carbon taxes or cap and trade systems (C&T) are used to drive up the cost of carbon and reduce emissions, this principle still holds. There are important differences between cap and trade and carbon tax systems, but for the purposes of this paper, the only one that matters is fiscal. A carbon tax, by definition, gives rise to government revenues. C&T systems need not. For our purposes, we will assume that governments would sell emissions permits to obtain an equivalent quantity reduction, so the C&T and carbon tax would have the same revenue implications. Therefore, for simplicity, we discuss carbon taxes in this paper, and leave any discussion of the desirability of a tax vs. C&T outside our discussion.
7. This paper explores a third element of necessary policies—fiscal burden sharing, ie. Possible intergovernmental imbalances that would arise because different levels of government will be exposed to different combinations of higher costs and higher revenues. Discussions have already started regarding the international implications of burden sharing. This paper would delve into the question of intergovernmental burden sharing between sub-national governments, including municipal, and national governments, and to a lesser extent, the question of how to manage the interpersonal burden sharing within the national economy.

1.1 What is the Impact of High Cost Carbon on Local Government Finance?

High cost carbon affects municipal finances from the expenditure side. How significant an effect this will be depends on the functional responsibilities of local government. Interestingly, some of the most basic functions are also some of the most carbon intensive. For example, garbage collection/disposal, street lighting, water delivery, transit, and operating schools and other municipal buildings are energy intensive responsibilities of the local government.

High cost carbon could also affect the revenue side for municipalities. However, it is quite likely to be the case that municipalities' revenue bases are much less sensitive to energy costs than are their expenditure bases. Moreover, local government revenue sources are often not well structured to capture higher energy prices. For example, water charges in many places in India are charged as a fixed cess (fee) on top of property taxes, and would thus not have any ready mechanism for responding to higher energy costs. In contrast, solid waste collection fees, frequently charged out as a fixed percentage of the electricity bill might fare better. Likewise, Municipalities that receive a share of gasoline taxes, such as in Spain, could fare better than most of those in South Asia where taxation of energy has been kept at the federal level.

To make an assessment of the initial impact of higher carbon taxes on municipalities, the carbon content of their revenues and expenditures needs to be measured, along with the price sensitivity of both flows. A more general equilibrium assessment would look at the impact once higher carbon prices had worked their way through the price system to understand both the medium and longer term impacts. It is probable that unintended fiscal imbalances could be provoked at the sub-national, especially municipal, level due to higher carbon taxation, if there are no compensating measures designed into the tax system.

This paper uses municipal revenue and spending data to develop a simple model of the financial impacts of higher energy costs in various scenarios. The purpose of this exercise is to illustrate the direction of impacts and interactions that may occur in different municipal finance contexts. This rough modeling exercise is intended to sensitize local, central and provincial governments to the likely implications of higher energy prices so that appropriate compensatory measures are considered as part of an overall package of policies for mitigating GHG emissions. Without such measures, there are likely to be unintended consequences that could include a rapid run up of municipal indebtedness or cutbacks of services—all of which might be avoided by properly redistributing tax revenues across levels of government.

2. REVIEW OF THE LITERATURE

A large literature already exists on the establishment of an environmental tax and its impact on economy. However, this literature rarely takes into account the case of the developing countries. Moreover, if a literature on the relation between governmental tax and sub national government tax exists, in the case of environmental tax this analysis is almost always posed in the context of unitary government. All this literature seeks to evaluate the optimal environmental tax. Major contributions to this end have been made by Bovenber, Goulder, Parry and many co-authors in the mid 1990's using general equilibrium system.

The relations between national government taxation and sub-national government can be found in the work of Besley and Rosen on the vertical externalities in tax setting with the cases of gasoline and cigarettes taxes. Estimating the magnitude of the responses of federal tax when federal government increases its taxes, they find that there is a significant positive response of state taxes. However they suggest more research to estimate how analyses of efficiency consequences of federal excise taxes would change when effects upon state tax rates are taken into account. They also warn us that if a positive interdependence between federal and state tax rates exists, then there is a risk that non-cooperative tax setting between federal and state governments results in excessive taxation of common tax bases. Fredriksson and Mamun (2007) also study the vertical externalities in cigarette taxation. They suggest that an increase in the federal cigarette tax may reduce the average state cigarette tax rate. They conclude that a federal tax hike may reduce state tax revenue via declines in two areas: the state tax base and the state tax rate.

Not many works have been done related to our subject in the case of developing countries. However, we can quote the work of Raja Chelliah and his book "Ecotaxes" on the question of environmental tax. On matter of sub-national government finance and intergovernmental transfers, we can quote the work Anwar Shah with his guide to intergovernmental fiscal transfers. Another work linked to our subject is the paper of Ahmad and Stern on effective carbon taxes and public policy options. This paper based on the Indian case evaluates which level of government might be responsible for the administration of this kind of tax. Their conclusion is that such a tax has to be a central excise and that it is not desirable to introduce differentiation into state level VAT's, at least for the Indian case. Their conclusion corresponds to our start point for this paper, which is a tax administered at a central level and harmonized between all the countries.

3. Structure of Municipal Finances

To examine the questions described above regarding the impact of higher energy costs on municipalities, we considered two different groups of municipalities, those in Maharashtra, India and those in Spain. For both sets of municipalities, we have reasonably detailed data on the structure of expenditures and revenues. The data for Spain are at the national level, thus covering all municipalities. For India, no such data exists, so we validated this data by comparing it with somewhat more aggregated data from Kundu (2002) for the city of Ahmedabad, and from Mohanty and others (2007) for the 35 metropolitan cities in India. The structure of expenditures and the types of revenue sources in both these alternative data sources, while more aggregated than our Maharashtra data, appear reasonably similar, which gives us some confidence that the more detailed Maharashtra data is representative.

These two examples represent systems that differ in important aspects, including the sources of revenues, the structure of functions devolved and spending, among others. A good knowledge of the structure of municipalities' expenditure is essential to understand how their finances will be affected by a fluctuation of the energy price. Since there appears to be no direct measurement of energy consumption for municipalities in either country, we approximate the energy consumption by separating into different categories the different type of expenditures by intensity of energy consumption. We have also reviewed the structure of revenue flows, to understand which of these may be sensitive to energy prices.

3.1 Revenue

India and Spain have both decentralized many functions to sub national government: states for India and provinces for Spain. However, there is a considerable difference in how the municipalities are financed in India and in Spain. Spain is examined as a whole because most Spanish municipalities have similar revenue structures (except for the Basque province). For India we choose to study the Maharashtra State, because the State Finance Commission of this state made a great effort to collect data on municipalities' finances--work that only a few Indian states have made so accurately.

For the Spanish municipalities' finances we relied on the interesting work of DEXIA[3] on finances and competences on sub national government in the European Union.

3.1.1 Spanish Municipalities

In Spain in 2005, 23% of the sub-national governments' revenue went to municipalities, which represents the amount of 43 EUR billion, or 4% of GDP. The revenue came fairly equally from taxes (33%), grants (36%) and other sources such as fees and asset sales (31%), as shown in Table 1.

TABLE 1
Sources of Revenue for Spanish Municipalities

Spanish Municipalities Revenue in 2005	€ MM*	% of Total Revenue
Tax revenue	14 201	33,1
of which own-source tax	(13 482)	(31,4)
of which shared tax	(719)	(1,7)
Grants	15 540	36,2
of which general grants	(7 085)	(16,5)
of which earmarked grants	(8 455)	(19,7)
Other	13 132	30,6
of which asset sales	(106)	(0,2)
of which fees	(8 094)	(18,9)
Total	42 873	99,9

Source: DEXIA (2005). *MM = Million

[3]DEXIA, Collective work under the direction of Dominique Hoorens, (2008) : **Sub-national government in the European Union**. DEXIA Editions, July 2008

Tax Revenue

Spanish municipalities have own taxes revenue and revenue from shared taxes. Their own taxes represent 95% of municipal tax revenue. Municipalities raise several local taxes, the most important are shown in Table 2, below:

TABLE 2
Own-Source Tax Revenue for Spanish Municipalities

Own-Source Tax Revenue	Municipalities		
	€ MM	% of Tax Revenue	% of Total Municipal Revenue
Tax on property	6 800	48	16
Tax on construction, installations and works	2 200	15	5
Tax on motor vehicles	2 000	14	5
Tax on economic activities	1 300	9	3
Tax on capital gains in urban areas	1 200	9	3
Total	13 500	95	32

Source: DEXIA (2005). *MM = Million

Municipalities with more than 75 000 inhabitants and capitals of provinces receive shared tax receipts. A summary of these shared tax revenues are shown in Table 3:

TABLE 3
Shared Tax Revenue for Spanish Municipalities

Shared Tax Revenue	Municipalities		
	€ MM	% of Tax Revenue	% of Total Municipal Revenue
1,7% of the Personal Income Tax	370	2,6	0,9
1,8% of the VAT	250	1,8	0,6
2,0% of the excise taxes	99	0,7	0,2
Total	719	5,1	1,7

Source: DEXIA (2005). *MM = Million

There are several pathways through which energy price increases could affect this municipal revenue base. For own-source revenues, however, all of these would be second order effects, since none of the revenues are directly tied to energy prices. These second order effects could be significant if, for example, the relative price of housing and motor vehicles, for example, were to decline in the face of higher energy prices. A Computable General Equilibrium model (CGE) would be an excellent tool for exploring these impacts. In this simplified model, municipal own-source revenue is assumed to be unaffected by fluctuations in the price of energy. However, in the case of Spain, we consider that the shared excise taxes fluctuate with the fluctuation of the price of energy because this tax includes a hydrocarbon tax. Currently, this excise is a per unit charge, and would thus not fluctuate with energy prices. However, a carbon tax that is ad valorem, could at least be shared following the current sharing principle.

Grants

Municipalities receive an unconditional grant from the central government: the municipal share of the State Tax (Criteria are population, fiscal effort and the inverse of fiscal capacity). It represents 17% of total revenues.

Municipalities also receive earmarked grants for specific investment projects such as transport infrastructure. They represent 20% of total revenues.

Other revenue

User charges on services or administrative functions supplied to all citizens, fees and asset sales are the other sources of financing available to Spanish municipalities.

3.1.2 Indian Municipalities (Maharashtra)

Maharashtra has two forms of Urban Local Bodies (ULB): Municipal Corporations and Class Municipal Councils. The Municipal Corporations include megacities like Mumbai which are interesting in their own right, but quite different from the smaller cities and towns covered in the Municipal Councils. Class Municipal Councils form depend on the population. In Maharashtra there are three types: 'A', 'B' and 'C' municipal councils representing in this order the most populous cities to the least[4]. We amalgamated the sum of incomes and expenditures of the three types of municipal councils.

The structure of revenues in Maharashtra is different from the Spanish municipalities. Grants from the state government represent two-thirds (64%) of the total revenue for municipalities in Maharashtra (compared to 37% in Spain), whereas

[4]The budgets for Spanish municipalities taken from Dexia include capital budget items. However for the Indian municipalities, the capital budget items were insignificant and fluctuated greatly across municipalities and over time. Since we were concerned with the reliability of this data, we did not include capital budget items on either the cost or revenue side for the Maharashtra municipalities.

own Source Tax revenue represents just 17% of the total. This is partly a consequence of the difficulty to collect taxes for Indian municipalities. Moreover, the absence of a system of shared taxes explains why grants in municipalities' revenue are so important. The general revenue structure and a breakdown of Maharashtra own-source tax revenues are shown in Table 4 and Table 5 respectively.

TABLE 4
Sources of Revenue for Maharashtra Municipalities

Municipalities Revenue in 2000	Rs.MM	% of Total Revenue
Tax revenue	1 875	16,6%
Grants	7 272	64,2%
Other	2 178	19,2%
Total	11 326	100,0%

Source: Maharashtra State Finance Commission (2000).

Tax Revenue
Indian municipalities have own taxes revenue but no revenue from shared taxation. Municipalities raise several local taxes, the most important are the following:

TABLE 5
Own-Source Tax Revenue for Maharashtra Municipalities

Own-Source Tax Revenue	Municipalities		
	Rs.Mm	% of Tax Revenue	% of Total Municipal Revenue
Property Tax	1,038	55	9,2
Water Charges	578	31	5,1
Conservancy and Sanitation	21	1	0,2
Street Lights	0,1	0	0,0
License Fees and Entertainment	67	4	0,6
Building Rents	171	9	1,5
Total	1 875	100	16,6

Source: Maharashtra State Finance Commission (2000).

Grants

Grants from the States represent 64% of municipalities' revenue. Municipalities receive financing from about 30 state grants. Most of these grants are for specific purposes, although incentive grants are provided to encourage better performance in collecting water charges and property taxes. The most important grants are: Dearness Allowance Grant, Grant for reimbursement of salary and leave salary of Chief Officers, Land revenue and non agriculture assessment grant, Entertainment Grant, Stamp Duty Grant, Pilgrim Tax, Minor Mineral Grant, Profession Tax Grant, Road Grant, Octroi Compensation Grant (Octroi have been abolished in 2000), Primary Education Grant, Slum Improvement, Incentive Grant.

Many of these grants compensate municipalities for local taxing powers that were repealed, most notably octroi. The principles upon which they are distributed are not uniform, and often times are *ad hoc*. This lack of predictability affects planning of expenditure strategies for municipalities.

Other Revenue

Other revenue represents 19% of municipalities' revenue. These sources include parking fees, permit fees, service fees and user charges, rent from commercial complexes, development fees for granting permission to construct buildings on vacant plot, and other fees and charges etc.

3.2 Expenditures

Here we explore expenditures for Spanish and Indian municipalities side-by-side. The structure of expenditure is very different between Spanish and Indian municipalities. Whereas Spanish municipalities spend 30% of their revenue in capital expenditure, almost all the revenue of Indian municipalities is spent in current expenditure, most of which is dedicated to staff cost.

Functions assumed by municipalities are not the same either, even if there are some in common such as water supply, garbage collection etc… However these common expenditures do not represent the same percentage of the total expenditure in the two countries. In the following we will detail these expenditures under the point of view of energy consumption.

In 2005, Spanish municipalities' expenditure reached 43.5 EUR billion, which represents 13% of total public expenditure in Spain, and 4.5% of GDP. These ratios are among the highest in the European Union. 70% of municipalities' expenditure is current expenditure, of which 45% (representing 30.6% of total expenditures) is staff costs. The remaining 30% are capital expenditure.

In contrast, municipalities' expenditure in Maharashtra, India reached 11 121 Rs.MM. This expenditure is almost entirely current expenditure, as the reported capital expenditure is minimal.

Municipal expenditures for India and Spain have been itemized by function and are shown in Table 6 and Table 7, respectively. It should be noted that for

India, differentiation is made between obligatory functions such as water supply, fire brigades and street lighting, versus discretionary functions such as urban poverty alleviation and destruction of harmful animals. For both Spain and India, it is expected that different municipal functions will require energy inputs at varying degrees of intensity.

Unfortunately, there is little published data on the actual use of energy in different municipal functions. This is because separate activities are often not ring-fenced and actual energy usage is not tracked. Therefore, we imputed energy intensities to different activities based on the likely profile of energy use. To do so, we created three different categories of spending based on energy intensity of total spending, and made reasonable assumptions about the extent of energy use in each, which we then vary later in sensitivity testing. We categorized the different functions according to percentage of costs incurred for energy: insignificant (0%), significant (20%) and intense (90%). These imputed intensities reflect fairly conservative assumptions on intensity of energy use by category.

TABLE 6
Energy Intensity of Municipal Expenditures in Maharashtra, India

Energy Consumption	Sector	% of Total Expenditure	Budget (Rs.Mm)
Insignificant	General Administration, Salaries, Pension & Pensionary Benefits etc	28,7%	3 389
	Administration of Shops & Establishment Act 1948, & Markets (D)	0,3%	35
	total	29%	3 423
Significant	Fire Brigade (O)	0,3%	32
	Slaughter Houses (D)	0,0%	4
	Education, Libraries,Free Reading Halls etc. (D)	9,3%	1 099
	Museums, Art Galleries, Recreation Centres, Playgrounds, Gardens etc. (D)	0,7%	87
	Epidemics & Public Health (O)	1,4%	169
	Other Expenditure	32,8%	3 873
	total	45%	5 263
Intense	Roads (O)	8,1%	953
	Street Lighting (O)	3,3%	386
	Sanitation, Solid Waste Management & Drain, Mechanical & Electrical etc (O)	5,6%	664
	Water Supply (O)	9,6%	1 133
	total	27%	3 137
Total		100%	11 822

TABLE 7
Energy Intensity of Municipal Expenditures in Spain

Energy Consumption	Sector	% of Total Expenditure	Budget (€ MM)
1. Insignificant	General public services	33	16 432
	Social protection	8	4 068
	total	42	20 500
2. Significant	Education	5	2 200
	Health	1	622
	Recreation, culture and religion	11	5 351
	Public order and safety	8	3 882
	total	25	12 055
3. Intense	Housing and community amenities	10	4 693
	Economic affairs	14	6 998
	Environment protection	10	4 993
	total	34	16 684
Total		100	49 239

We used the same coefficients for the municipalities in Spain and India for simplicity, since there is little data available to determine whether these differ. Thus what drives the differences between the two is the distribution of spending by function. Of course, with better data, such estimates could be refined.

In comparison to Spanish municipalities, we observe that the share of functions not using energy is more important in the Spanish case than the Indian. This is somewhat surprising given that a large share of Indian municipality spending is for payrolls. Actually the difference is the share of spending for services that use little energy. Spanish municipalities have program of social protection, it represents almost 10% of their expenditure. In Indian municipalities the amounts spent on that type of programs is much smaller.

By contrast, a larger share of the Indian municipalities' spending is for activities where the consumption of energy is significant. This is due to the important number of public buildings that require energy for heating and cooling as well as public transport which appears in the category "other expenditure".[5] Since public transport and environment are important items in this category, we chose to categorize this spending as having a "significant" energy content, i.e. 20%.

[5]Unfortunately, the expenditure accounts of Indian municipalities include a large item (other expenditures) greater than 30% of total, which includes a large number of disparate items. More breakdown of those items would be needed to get a better sense of how energy intensive spending is.

Functions with an intense consumption of energy are more important in Spain mainly due to the amounts spent on public transport infrastructures, industry, communication etc…and construction and upkeep of social housing which do not exist in India municipal expenditures. Functions of Indian municipalities which appear in this category are essentially water supply, garbage collection, street lighting and sewage, representing 27% of total expenditure.

Using the breakdown of spending and assumptions with regard to energy intensity, we find that despite all of the differences in the basic structure, both sets of municipalities (Spain and India) end up with roughly one-third of spending being energy price sensitive.

4. ECONOMIC MODEL

We now present the model used to simulate the impacts of higher energy prices on municipalities' finances with a view to understanding the effects of policies that increase the price of traditional energy. For these simulations, we will establish three different scenarios. In the first one, we allow municipalities to increase their deficit in the face of higher energy costs. This implicitly assumes that higher deficits can be financed. In the second one and the third, the initial deficit will be constant, and municipalities will have to decide to make cuts in their expenditure.

To simplify, we will consider only two prices. First the average unit price of energy (whatever the source of energy) P_E in municipal expenditures. The other price P_{NE} is the average unit price of all the municipal expenditures except energy goods.

At these prices are associated quantities. Q_E is the quantity spending on energy and Q_{NE} the quantity of spending that do not consume energy.

<u>Notations:</u>

P_E: Unit price of energy
P_{NE}: Unit price of municipal expenditures not linked to energy

Q_E: Quantity of spending on energy
Q_{NE}: Quantity of spending that do not consume energy

R: Municipalities revenue
- R_E : Revenues linked to energy prices
- R_{NE}: Revenues not affected by energy prices

E: Municipalities expenditure

E_E: Expenditures only linked to energy prices

E_{NE}: Expenditures not affected by energy prices

X: Municipalities deficit

Equations:

$E_i = P_i \cdot Q_i$ (Equation of expenditure)

$R + X = E$ (Budgetary equation)

4.1 Scenario 1: Deficit Endogenous

In this scenario we consider the deficit as an endogenous variable. Q_E is also a endogenous variable which depend on the fluctuation of the energy price with an elasticity ε . P_E', the new energy price, is the exogenous variable. All the rest is constant. The aim is to highlight the impact of fluctuation in energy price on the municipalities' deficit. The full derivation of the following equations has been omitted, but can be obtained by contacting the authors.

The budgetary equation is: $P_E \cdot Q_E + P_{NE} \cdot Q_{NE} = R + X = E$

We shock the price of energy:
$P_E \cdot Q_E + \Delta (P_E \cdot Q_E) + P_{NE} \cdot Q_{NE} = R + X + \Delta (R + X) = E + \Delta E$

The new budgetary equation is: $P_E' \cdot Q_E' + P_{NE} \cdot Q_{NE} = E'$

With :

- $P_E' = P_E + \eta$
- $Q_E' = \left[\varepsilon \cdot \left(\frac{P_E'}{P_E} - 1\right) + 1\right] \cdot Q_E$
- $E' = R' + X'$

Then we have two different cases due to structural differences between Spanish and Indian municipalities' sources of income.

Indian case :
Incomes of Indian municipalities are not sensitive to the price of energy. Thus energy prices only affect the cost base and spending: $R' = R$, and $X' = E' - R$

We have therefore the new deficit:

$$X' = P_E'.\left[\varepsilon.\left(\frac{P_E'}{P_E} - 1\right) + 1\right].Q_E + P_{NE}.Q_{NE} - R$$

Spanish case:
Spanish case is more complex because some of the municipal incomes came from shared tax which is linked to the hydrocarbon price. Municipal incomes are therefore composed of a part which is not linked with energy price, and another which fluctuate with the price of energy (with an elasticity ε_R):
$R = R_E + R_{NE}$

with elasticity: $\varepsilon_R = \dfrac{\frac{\Delta R_E}{R_E}}{\frac{\Delta P_E}{P_E}}$

After several intermediate steps, the form of the new incomes is given by:
$R' = R_{NE} + R_E'$

With: $R' = R + \Delta R$ and $R_E' = R_E\left[1 + \varepsilon_R \cdot \left(\frac{P_E'}{P_E} - 1\right)\right]$

For the simulation, we will take: $\varepsilon_{R=1}$. This merely assumes that any increase in energy prices and tax revenues will be passed through fully in the taxes shared with the municipalities. As municipal revenues increase, they must decide how to spread income between the two types of spending, energy sensitive and non-energy sensitive. We assumed to share this increase in income between energy and non-energy expenditures according to their share in total spending after the price shock.

a is the percentage of new energy expenditure in total new expenditure:

$$a = \frac{P_E'.Q_E'}{E'}$$

And *b* is the percentage of non-energy expenditure in total new expenditure:

$$b = \frac{P_{NE}.Q_{NE}}{E'}$$

Finally :

$$E_E' = P_E' \cdot Q_E' - a \cdot \Delta R$$

$$E_{NE}' = P_{NE} \cdot Q_{NE} = b \cdot \Delta R$$

And :
$$X' = E_E' \cdot E_{NE}' - R$$

4.2 Scenario 2: Non-Energy Expenditures Endogenous

In this scenario, we consider the municipal deficit as a constant—a municipality cannot increase its deficit. With this consideration, the quantity Q_{NE} becomes an endogenous variable of the model. However the elasticity of Q_{NE} face to P_E is considered to be zero. Q_E remains an endogenous variable and P_E an exogenous one. All the rest is constant.

Equations and development are the same than for the scenario 1, except that Q_{NE} has became the endogenous variable instead of E. Therefore we obtain:

$$P_E' \,.\, Q_E' + P_{NE} \,.\, Q_{NE}' = E$$

With:

- $P_E' = P_E + \eta$
- $Q_E' = \left[\varepsilon \cdot \left(\frac{P_E'}{P_E} - 1\right) + 1\right] \cdot Q_E$
- $Q_{NE}' \quad \frac{E - P_E' \cdot Q_{NE}'}{P_{NE}}$

Indian case: In the Indian case, this is the final equation.

Spanish case: In the Spanish case, we still have the incomes which are endogenous.

Then:

$$P_E' \cdot Q_E' = P_E' \cdot Q_E' - a \cdot \Delta R$$

$$P_{NE} \cdot Q_{NE}' = P_{NE} \cdot Q_{NE} - b \cdot \Delta R$$

With a and b the percentages of non-energy expenditure in total expenditure if the total expenditure was endogenous variable.

We finally obtain:

$$Q_{NE}' = \frac{E - P_E' \cdot \left(Q_E' - a \dfrac{\Delta R}{P_E'} \right)}{P_{NE}}$$

4.3 Scenario 3: Non-Energy Spending Endogenous, Redistribution of Expenditure Shares

This scenario is similar to the scenario 2 because deficit is a constant and Q_{NE} an endogenous variable. Difference is that we consider that the cost of this fluctuation in energy price on quantity of goods and services supply by municipalities will be redistributed between quantities spending on energy and non energy. In this case, the local government chooses to keep the part of each energy and non energy expenditures in total expenditure after the shock of the energy price constant.

$$P_E' \cdot Q_E' + P_{NE} \cdot Q_{NE} = E'$$

With :

- $P_E' = P_E + \eta$
- $Q_E' = \left[\varepsilon \cdot \left(\dfrac{P_E'}{P_E} - 1 \right) + 1 \right] \cdot Q_E$

α is the percentage of energy expenditure in new total expenditure, and β the one of non energy expenditure :

$$\alpha = \frac{P_E' . Q_E'}{E'} \qquad \beta = \frac{P_{NE} . Q_{NE}}{E'}$$

The final equation is given as:

$$Q_{NE}' = \frac{E - P_E' . \left(Q_E' - a \dfrac{\Delta R}{P_E'} \right)}{P_{NE}}$$

With :

- $P_E' = P_E + \eta$
- $Q_E' = \left[\varepsilon \cdot \left(\dfrac{P_E'}{P_E} - 1 \right) + 1 \right] \cdot Q_E$
- ΔE the variation of total expenditure if E would be an endogenous variable

Indian case: In the Indian case, this is the final equation.

Spanish case: In the Spanish case, we still have the incomes which are endogenous. So we finally obtain on the same structure than equation founded in scenario 2:

$$Q_{NE}' = \frac{E - P_E' \cdot \left(Q_E' - \alpha \dfrac{\Delta E}{P_E'} - a \dfrac{\Delta R}{P_E'} \right)}{P_{NE}}$$

5. SIMULATIONS AND RESULTS

Using the preceding economic model, we simulated the three scenarios with different parameters to evaluate the impact of an increase of the energy prices on municipalities' finance. In this part we will discuss the results, bringing back the model results to the reality facts. We will also analyze the influence of the different parameters on the model.

5.1 Initial Conditions

First of all we input the initial conditions for the two different types of municipalities of our model.

TABLE 8
Initial Conditions for Economic Model of Maharashtra Municipalities

India	R (Incomes)	113 259	Part of energy consumption:	Insignificant:	0%
(Rs.Lakhs)	E (Expenditures)	118 221		Significant :	20%
				Intense :	90%
	X (Deficit)	4 962			
	Ee (Energy expenditure)	38 754	Qe (Quantity of energy consumed)	38 754	
	Ene (Non energy expenditure)	79 467	Qne (Quantity of non energy goods consumed)	79 467	

TABLE 9
Initial Conditions for Economic Model of Spanish Municipalities

Spain	R (Incomes)	42 873	Part of energy consumption :	Insignificant:	0%
(€ MM)	E (Expenditures)	49 239		Significant:	20%
				Intense:	90%
	X (Deficit)	6 366			
	Ee (Energy expenditure)	17 427	Qe (Quantity of energy consumed)	17 427	
	Ene (Non energy expenditure)	31 812	Qne (Quantity of non energy goods consumed)	31 812	

Initially the unit prices of energy and non energy good are input to value 1. That explains the equality between quantities and expenditures in these charts.

The types of municipalities in India and Spain are too different to compare the sums that appear in these charts. We can, however, compare the distribution of the finances. The part of Ee[6] and Ene[7] in the total expenditure are almost the same for India and Spain as we saw in the structure of municipalities (see chapter -II-). By contrary, the ratio deficit over expenditure X/E is much higher in the Spanish case. That will have consequence on the increase of deficit in the scenario 1. Of courses it is possible that this ratio is undervalued in the Indian case with a deficit relatively low. But this fact will not influence the aim of our results as we work on the comportment of the deficit face to a shock of energy price and not its original level.

Elasticity of the municipalities' quantity of energy good face to the price of energy is an important parameter. In the literature we found elasticity around -0.4 and -0.2 (depend on long/short term: -0.2 short term provided by INSEE[8] and the RAND[9]) for individuals.

---

[6]Expenditure on energy.

[7]Spending on good not using energy.

[8]INSEE : Institue National de la Statistique et des Etudes Economiques. French national institute for statistic and economic studies. Danielle Besson, Insee (2008) : **Consommation d'énergie : autant de dépenses en carburants qu'en énergie domestique**. Insee Première N°1176, février 2008.

[9]The RAND Corporation is a nonprofit research organization providing objective analysis and effective solutions that address the challenges facing the public and private sectors around the world. Michael Toman, James Griffin, Robert J. Lempert, (2008) : **Impacts on U.S. Energy Expenditures and Greenhouse-Gas Emissions of Increasing Renewable-Energy Use**. Published 2008 by the RAND Corporation.

We expect a municipality to have lower short term price elasticity for energy spending, since reducing energy expenditures could involve reductions of critical public services like street lighting and garbage collection. Soft options like using public transport rather than a car are not possible for these public services. But with time and technological progress this elasticity will become higher in absolute terms. That is why we will separate short term and long term. Short term will be assigned an elasticity of -0.1 and long term -0.4 which represent extreme values.

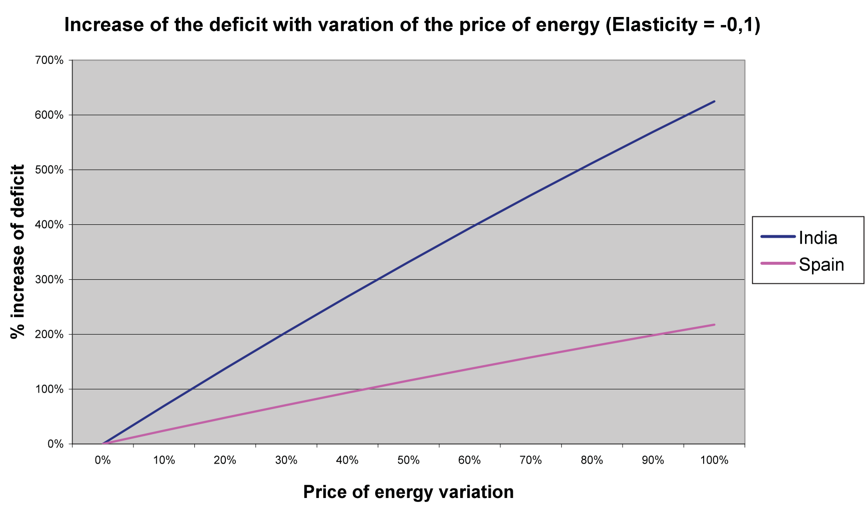
5.2 Simulations and Results Scenario 1

In scenario 1 the deficit is endogenous. This means that municipalities are able to borrow to finance an increase in their deficit which bears the brunt of the increase in the price of energy. Municipalities refuse to reduce their spending on goods non using energy, and the reduction of their spending on energy in just influence by the elasticity and no other political reason.

Results:

5.2.1 Short term: Elasticity = -0.1

FIGURE 1
Short-Term Impact of Energy Price Variation on Municipal Deficit

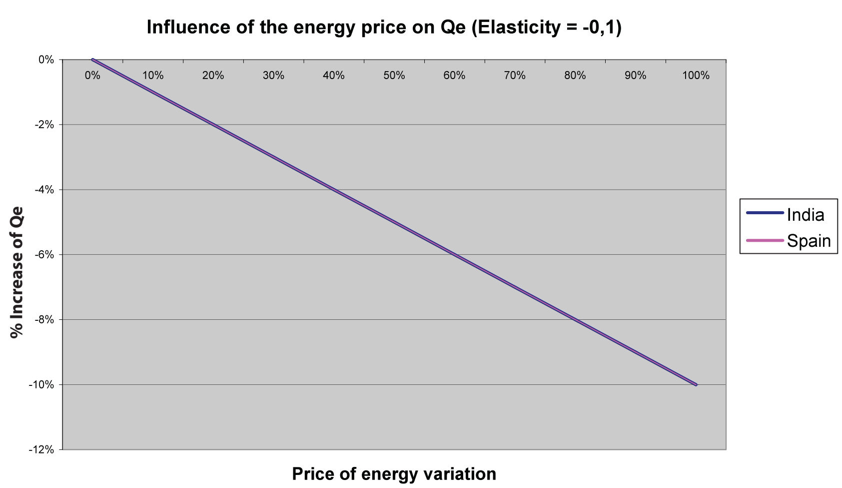


As it was predictable, the deficit increases with the increase of the price of energy. First observation is that for an increase of 20% of the price of energy, deficits in India (Maharashtra) rose by 140% and by 50% in the Spanish case (see Figure 6). It is therefore easily understandable that a municipality cannot sustain such an increase of energy price. An increase of 5% already leads to an increase of 50% of the deficits in India. Expenditures are too sensitive to energy price to be able to sustain an increase of 5%. The intuition behind this result is essentially that in municipalities with limited resources and functions and financial capacity, their deficit is relatively small in relation to their energy related spending. A significant increase in the price of energy could put them in financial distress.

The percentage impact on the deficit in Spain is much less significant for the same increase in the energy price, even though the percentage of spending that linked to the price of energy is relatively similar. This is because the baseline Spanish municipalities' deficit in relation to total spending is much higher, indicating significantly more access to deficit finance than in the Indian case. That explains that the increase of deficit is lower in the Spanish case. Figure Omitted illustrates this by tracking the ratio of the deficit to total expenditure as the energy price increases. This ratio moves similarly for both Spanish and Indian municipalities.

If we examine the quantity of energy consumed (see Figure 7), we first note that both groups reduce energy use substantially even though energy spending increases. Because of the relatively low elasticity with respect to price, the price increase much outpaces the capacity to conserve on the quantity of energy consumed, at a rate of 10 to 1 for an elasticity of 0.1.

FIGURE 2
Short-Term Impact of Energy Price Variation on Quantity of Energy Expenditures



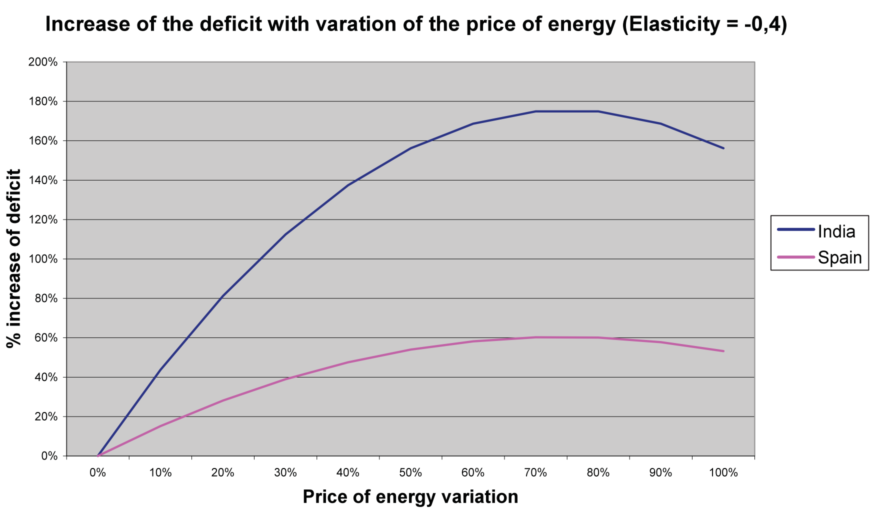
To summarize scenario 1, for the short term, a small increase of energy price has the desired effect of reducing the quantity of energy consumed, although it is quite limited. This comes at the cost of an increase in the deficit for both sets of municipalities, a very dramatic one in the Indian model. The impact of the shared tax on energy is limited because it is very small in relation to the increase in spending. If we examine Spain with and without this shared tax, the increase of deficit is 1% lower for a 70% increase in the price of energy.

5.2.2 Long term: Elasticity = -0.4

Over the long term, with technical progress and investments in new technologies, municipalities are better able to reduce consumption in the face of higher energy prices. We represent this longer term scenario by increasing the price elasticity to -0.4. The results are shown in Figure 8 below.

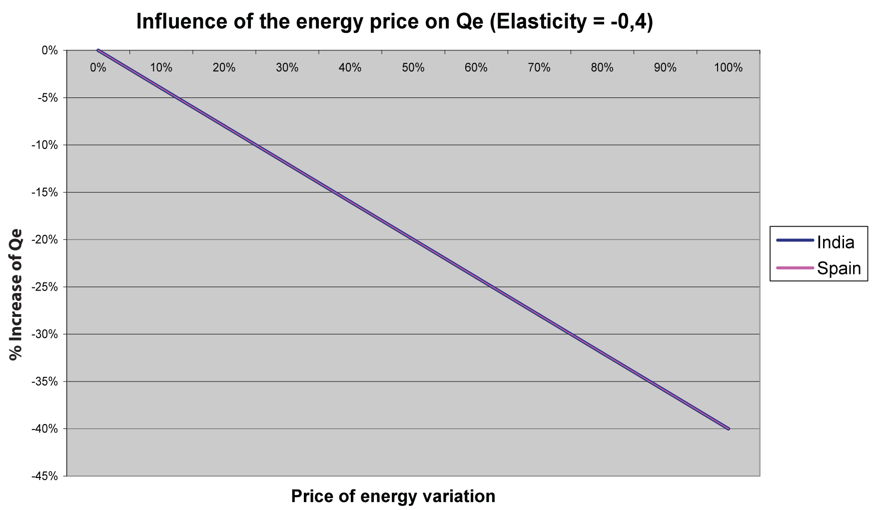
Before discussing the results, it is worth noting that there is nothing automatic about moving from the short to the long term scenario. As we saw above, municipalities will face chronic deficits as a result of energy price increases, and will thus have no fiscal space for investment in energy efficient technologies. Their creditworthiness ratios will all be deteriorating as spending increases, yet they will need to borrow to finance current spending. Without some concessional finance or grants, it is hard to imagine moving to this longer term scenario.

FIGURE 3
Long-Term Impact of Energy Price Variation on Municipal Deficit



In the long terms with an elasticity of -0.4 we see that the impact of an increase of energy price on deficit is, as expected much less than in the previous case. This time for an increase of 20% of the price of energy, deficits in India rose by 80% and by 30% in the Spanish case (see Figure 8), as opposed to 140% and 50% in the previous case. The quantity of energy consumed declines much more than in the earlier case (see Figure 9). This scenario illustrates that the longer term impact on municipalities' deficit is much less serious, although still substantial, provided they are able to invest in energy saving technologies.

FIGURE 4
Long-Term Impact of Energy Price Variation on Quantity of Energy Expenditures



5.3 Simulations and Results Scenario 2: Fixed Fiscal Deficit

In scenario 2, we assume that municipalities are not able to expand borrowing to absorb the impacts of an energy price increase. The deficit remains fixed at its initial value and spending must be restructured to cope with higher energy costs. In this scenario, we assume that spending on energy based goods responds as in scenario 1, based on the elasticity with respect to price. All other spending is reduced to meet the fixed deficit target.

Results :

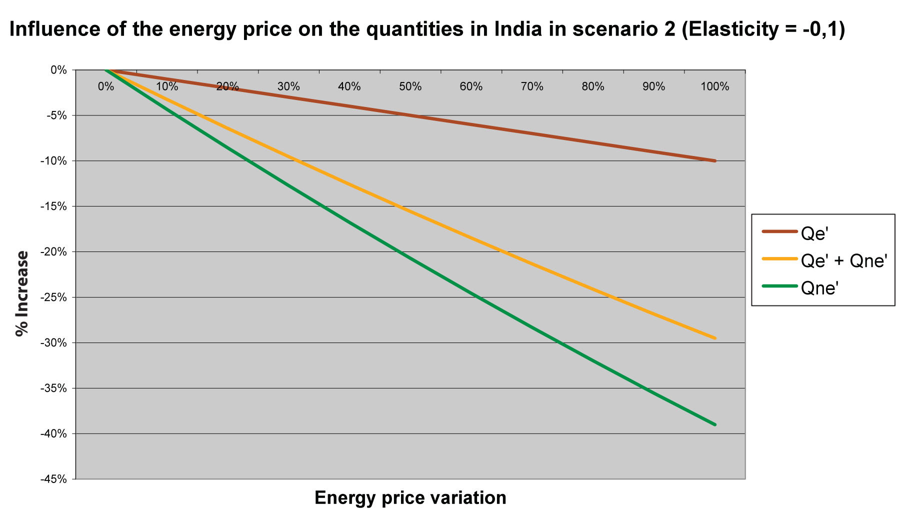
5.3.1 Short term : Elasticity = -0.1

In this scenario, the impact of an increase of energy price on the quantity spending on energy is the same as before. We still have a decrease of 1% of quantity for a 10% increase of energy price. Now it is the quantity spending on activities that do not use energy (Qne) that must be reduced to meet the deficit target. As discussed above, this would cover items like social welfare spending, salaries, including teachers in the case of Spain, and general administration. The intuition behind this formulation is that the energy spending is related to basic services that must be maintained. If fiscal restraint is needed, the salary bill, social safety nets and administration costs are more likely candidates for spending cuts.

This set of assumptions results in fairly dramatic cuts in non-energy spending. Qne decreases by close to 20% when the energy price rises by 50%. Such a 20% across the board cut in non-energy spending seems hardly conceivable for any municipality, even those most committed to belt tightening.

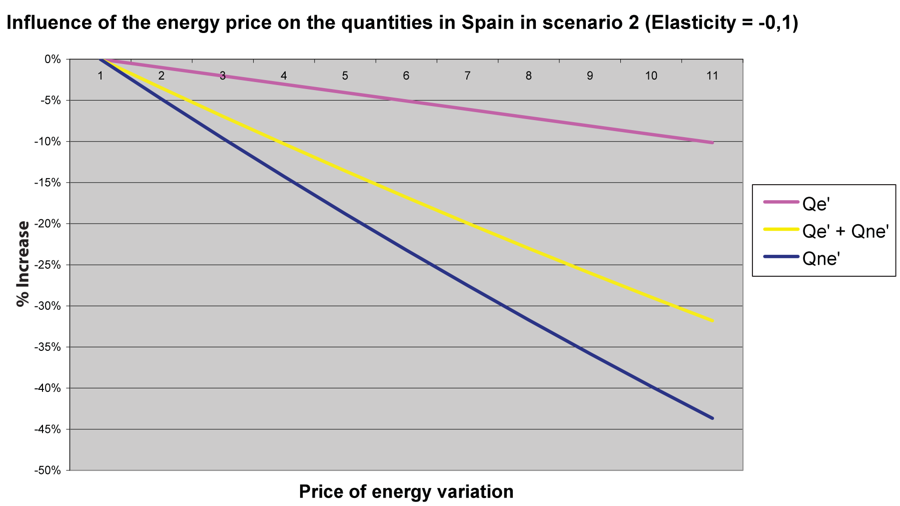
Figure 5 and Figure 6 show the quantities of goods and services provided by local governments in response to higher energy prices in a fixed deficit scenario. The first line Qe plus Qne shows the total impact of the higher prices on ability to spend. The two others show how it is divided between energy and non-energy if one seeks to protect energy public services and absorb the shock with more discre-

FIGURE 5
Short-Term Impact of Energy Price Variation on Municipal Expenditures in Maharashtra, India (Scenario 2)



tionary spending. It seems highly unlikely, however, that such dramatic cuts could actually be sustained. Hence it is more likely that spending in both areas would have to be cut in a scenario of strong fiscal restraint. This is examined in scenario 3.

FIGURE 6
Short-Term Impact of Energy Price Variation on Municipal Expenditures in Spain (Scenario 2)



5.4 Simulations and Results Scenario 3

This scenario is similar to the scenario 2 in that the municipalities' deficit is constant. The difference is that in this scenario the burden of an increase of energy price will be shared between the quantity spending on goods non-using energy (Qne) and quantity spending on energy (Qe). Now municipalities will choose to cut even more in their quantity of spending on energy to preserve a little more the quantity spending on goods non using energy (and so payroll and the wages). How do they choose to share the burden? Municipalities are assumed calculate their deficit as if they will be allowed to let it run after the price shock. They then reduce pro rata all expenditure categories by the same percentage to reach the desired new level of spending. The result is that Qe will decrease more significantly than in the scenario 2, and Qne will reduce less than in the previous scenario.

Results:

5.4.1 Short term : Elasticity = -0.1

As in the scenario 2, we follow the evolution of Qne. As expected the reduction of Qne is less important than in the scenario 2 (compare Figure 7 and Figure 8 with Figure 5 and Figure 6). For example, for a 50% increase of energy price, Qne decreases by 12% in scenario 3 whereas Qne decrease by 22% in scenario 2. The results are similar for both India and Spain. The wedge between the two scenarios increases as the energy price increases. Nonetheless even with this more even handed sharing of the pain of higher price increases, the burden on public services, social safety nets, and required reductions in salary bills is dramatic and hardly likely to be sustainable.

Of course, Qne is preserved because Qe decreases more rapidly than in scenario 2. If we take a look at the evolution of the total quantity (Qe + Qne), it decrease more rapidly than in scenario 2 for both Spanish and Indian municipalities. Overall, this shows there is no escaping the costs of higher energy prices. While scenario 3 is a more balanced strategy, if deficits cannot be accommodated, public services suffer considerably as energy becomes more expensive.

FIGURE 7
Short-Term Impact of Energy Price Variatiion on Municipal Expenditures in India (Scenario 3)

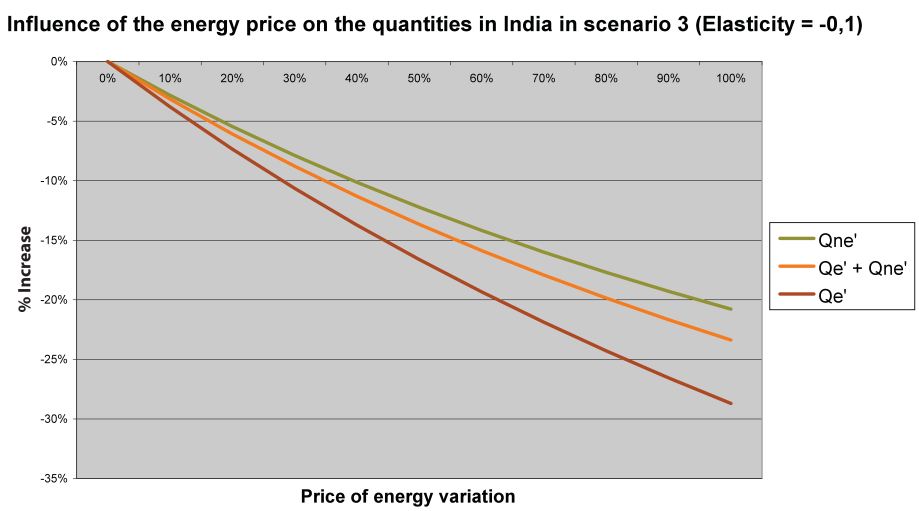
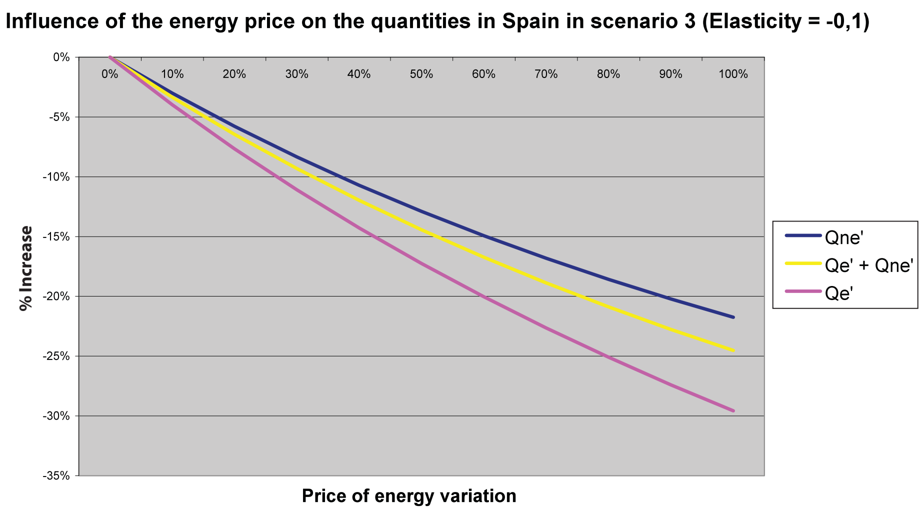


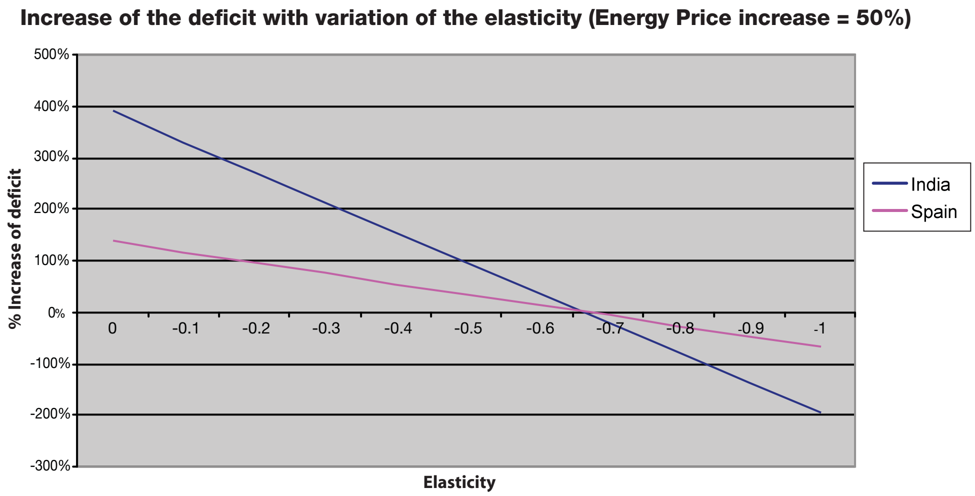
FIGURE 8
Short-Term Impact of Energy Price Variation on Municipal Expenditure in Spain (Scenario 3)



5.5 Sensitivity to the Elasticity Parameter

One of the most important parameters of the model is the elasticity of quantity of spending on energy with respect to the price of energy. To evaluate its influence on the model, we will see its impact on the deficit (scenario 1) for an increase of energy price by 50% (see Figure 9). As we see, elasticity has a strong influence on the increase of deficit. That is why we examined different values (-0.1 short term and-0.4 long term) to examine the impact on the deficit. The longer the period of adjustment, the higher one would expect the elasticity to be. This sensitivity thus illustrates that this problem is more one of a temporary adjustment, albeit over a period of decades most likely, provided assistance is provided to facilitate adoption of improved technologies that will in turn decline in price. This graph indicates that, at very high elasticities, ie in a very long term, responding effectively to higher energy prices can lower the overall energy bill for municipalities, and thus reduce a significant element in their cost base.

FIGURE 9
Sensitivity of Deficit to Elasticity of Expendituresof Energy Expenditures



6. CONCLUSIONS

This paper sought to examine the fiscal effects for local governments of very sensible policies for climate change, the most efficient policy for reducing GHG emissions applied economy-wide, that is, application of higher energy prices throughout the global economy to elicit reductions in GHG intensive energy use. These price changes are necessary to provide incentives to invest in energy saving technologies, to improve management practices etc. If designed correctly, such green taxes would provide a fiscal boon to government in general, because taxes (or their equivalent in auctioned permits) will bring substantial revenues to government.

What this paper does is look beyond the unitary government to examine the impacts for different levels of government with different taxation powers and different spending profiles. We used data on the spending and revenue profiles of two sets of local governments, those in Maharashtra, India, and those in Spain. In both cases, we found stylized facts that are quite representative of local governments world-wide. Local government revenues are not highly sensitive to the price of energy. Therefore, there will be no fiscal gain for local governments if energy prices increase, as they must do.

On the other hand, many of the public services that local governments provide are energy intensive. The ability to substitute away from using energy in providing these services is quite limited in the short term, even more limited than for individual consumers. For example, garbage cannot be hauled in public transport, but must instead rely upon conventional trucks until alternative technologies are available. So municipalities will have difficulty reducing their energy bills in the short term.

As a result, raising energy prices will create quite an adverse fiscal shock for local governments. Our analysis illustrates just how adverse this shock will be, and how the structure of spending affects the magnitude of the fiscal shock. Smaller, less diversified governments currently operating at a low level of service and with a very small operating deficit will be harder hit, precisely because the most basic services tend to be energy intensive, and their energy bill is high in relation to their current deficit financing envelope. However all municipalities would appear to be quite hard hit. Whether the shock is absorbed in deficit spending or in fiscal restraint, there will be a substantial shock. The pain results from the difficulty of reducing energy spending quickly in the short term.

The policy implications are clear, and they consist in reconsidering fiscal federalism in light of the climate change challenge. The level of government taxing energy will be running large surpluses corresponding to these dramatic fiscal crises provoked at the local level in the scenarios we have examined. Compensation for local governments hard hit by high energy bills makes sense both to protect the financial integrity of local governments and ensure reasonable service delivery. It makes a great deal more sense to compensate these local governments plunged into a crisis that is not of their own making using the extra funds generated at higher levels of government that are generating revenues from energy taxation.

This also makes more sense than the alternatives. Asking municipalities to cover these energy induced deficits by hiking their own taxes or charges would just involve burdening consumers already hit by higher energy prices for their own consumption and could quite likely lead to a tax payer rebellion. Asking them to reduce critical public services like solid waste management to meet a local budget constraint when surpluses are swelling at higher levels is counterproductive. It would also lead to an unintended increase in government saving that throws the overall government fiscal stance out of balance. This notion of compensation of local governments is similar to that which has been occasionally been proposed for private consumers hit by carbon taxes (or the impacts of a cap and trade system). There it has been argued that the carbon tax proceeds could be redistributed to the general public through a reduction in something like the payroll tax. The key is to find a reasonable compensation system that is not tied directly to energy spending, which would blunt incentives to conserve. Something like a poll credit (as opposed to a poll tax) might have the desirable properties.

References

Ahmad, Ehtisham and Nicholas Stern. 2008. Manuscript. "Effective Carbon Taxes and Public Policy Options, 2008."

Armar, Amarquaye and Pedro Paulo da Silva Filho. *Reducing Energy Costs in Municipal Water Supply Operations*. BNPP Publication, TF020499.

Besley, Timothy J., and Harvey S. Rosen. 1998. "Vertical Externalities in Tax Setting: Evidence from Gasoline and Cigarettes". *Journal of Public Economics* 70 (1998): 383–98.

Besson Danielle, Insee. 2008. *Consommation d'énergie : autant de dépenses en carburants qu'en énergie domestique*. Insee Première N°1176, février 2008.

Bovenberg, Lans and Lawrence H. Goulder. 1996. "Optimal Environmental Taxation in the Presence of Other Taxes: General- Equilibrium Analyses". *The American Economic Review* 86 (4) (Sep., 1996): 985–1000.

Bovenberg, Lans and Ruud A de Mooij. 1995**. "**Environmental Tax Reform and Endogenous Growth". *Journal of Public Economics* 63 (2) (January 1997): 207–37.

DEXIA, Collective work under the direction of Dominique Hoorens. 2008. "Sub-national Government in the European Union"**.** DEXIA Editions, July 2008.

Fredriksson, Per G. and Khawaja A. Mamun. 2008. "Vertical Externalities in Cigarette Taxation: Do Tax Revenues go up in Smoke?" Journal of Urban Economics 64 (2008): 35–48.

Goodstein, Eban. 2003. "The Death of the Pigovian Tax? Policy Implications from the Double-Dividend Debate" *Land Economics* 79 (3): 402–14.

Government of Maharashtra. 2002. *12th State Finance Commission***.**

Howarth, Richard B. 2005. "The Present Value Criterion and Environmental Taxation: The Suboptimality of First-Best Decision Rules"**.** *Land Economics* 81 (3): 321–36.

Kundu, Debolina. 2002. "Provision of Infrastructure and Basic Amenities: Analyzing Institutional Vulnerability." Chapter 4 in *Poverty and Vulnerability in a Globalizing Metropolis Ahmedabad*, ed. Kundu Amitabh and Mahadevia Darshini, Manak publications (2002).

Mohanty, P.K., B.M. Misra, Rajan Goyal, and P. D. Jeromi. 2007. "Municipal Finance in India: An Assessment" Development Research Group Study No. 26. Mumbai: Reserve Bank of India, Department of Economic Analysis and Policy.

Planning Commission, Government of India. 2005. *Draft Report of the Expert Committee on Integrated Energy Policy.*

Shah, Anwar. 2006. *A Practitioner's Guide to Intergovernmental Fiscal Transfers*. Washington, DC: World Bank Institute.

______. 1989. "A Linear Expenditure System Estimation of Local Fiscal Response to Provincial Transportation Grants". *Kentucky Journal of Economics and Business* 9 (1).

Toman, Michael, James Griffin and Robert J. Lempert. 2008. *Impacts on U.S. Energy Expenditures and Greenhouse-Gas Emissions of Increasing Renewable-Energy Use.* RAND Corporation.

CHAPTER 25

Mobilizing Private Sector Resources Toward Climate Adaptation and Mitigation Action in Asia

Jacob Park*

Summary

This paper will explore the current state of and future outlook for mobilizing private sector resources in the Asian post-climate 2012 policy context, with a special emphasis on the energy poor and environmentally fragile urban population. Two issues and questions will be explored in this paper. First, what is the current state of and future outlook for public and private investments to address global/Asian climate change concerns? Second, what new triple bottom line strategy of financing climate change action is required to respond more effectively to the urban climate change dilemma in Asia?

*Corresponding author: parkj@greenmtn.edu

1. INTRODUCTION

In the 15 years since the adoption of the Kyoto climate change protocol in 1997, increasing scientific concerns about climate change, growing inevitable sense of a global climate regulatory regime, and accelerating use of Kyoto Protocol market mechanisms have propelled many new types of private sector responses to global climate change around the world, ranging from energy efficiency and clean technology focused policy approaches, voluntary carbon mitigation programs, and mandatory emissions trading regimes.

There has also been a rapid increase in high level calls for increased financial resources devoted to climate adaptation and mitigation activities. Most notably, European Union proposed in Fall 2009 that the industrialized countries should give developing countries US$74 billion a year by 2020 and should begin with an annual US$7.5 to 10 billion from 2010 to 2012 in "fast start finance" (Barber 2009). Underscoring the serious financial dimensions of creating a long-term sustainable climate change solution, Oxfam (2009) stated in a recent report that an *additional* US$42 billion in humanitarian need will be urgently required to help developing countries adapt to the effects of climate change.

The urgency in which the funds are needed to address climate adaptation and mitigation activities are not contested; what is less clear is where the necessary funds will come from. This chapter[1] will explore the current state of and future outlook for mobilizing private sector resources (financial, technological, and organizational) in the Asian post-climate 2012 policy context, with a special emphasis on the energy poor/environmentally fragile urban population. While the percentage of climate projects sourced from Asia nearly doubled in 2007 and Asia continues to attract the bulk of the Clean Development Mechanism related investments, it remains unclear how and to what degree the relative health of the voluntary carbon market address the long-term sustainability needs of the Asian energy poor/environmentally insecure urban population. Two issues and questions will be explored in this chapter

First, what is the current state of and future outlook for public and private investments to address Asian climate change concerns? Finance is one of the building blocks of the Bali Action

Plan. Like other parts of the world, Asian countries will be under a lot of pressure to accelerate the mobilization of bilateral/multi-lateral aid and private investment flows to address regional climate change concerns. Second, what new triple bottom line strategy of financing climate change action is required to respond more effectively to the urban climate change dilemma in Asia? Since

[1]I gratefully acknowledge the support and comments received at the Institute for Global Environmental Strategies Policy Forum on Energy Security and Post-2012 Climate Regime Conference held in Bangkok, Thailand in August 2008 in shaping the analysis presented in this paper.

industry currently accounts for one-third of the energy consumed worldwide and growing carbon and energy footprint of China, India, and emerging Asian countries, there is a urgent need to improve our understanding of the complex global/Asian regional policy interplay between private sector and climate change governance as part of an overall goal to build a sustainable post-2012 climate policy framework.

2. CURRENT AND FUTURE OUTLOOK FOR PRIVATE AND PUBLIC INVESTMENTS TO ADDRESS GLOBAL AND ASIAN CLIMATE ACTIVITIES

2.1 Defining the Climate Adaptation and Mitigation Investment 'Need'

The Bali Action Plan stated the importance of mobilizing financial resources and investment to support climate change-related mitigation, adaptation and technology cooperation activities, including "improved access to adequate, predictable and sustainable financial resources and financial and technical support … mobilization of public- and private-sector funding and investment, including facilitation of carbon-friendly investment choices … financial and technical support for capacity-building in the assessment of the costs of adaptation in developing countries, in particular the most vulnerable one…" (Nakhooda 2008; UNFCC 2007a).

Despite the obvious importance, it is unclear what constitutes or how one might define a "sustainable" level of financial resources and investments in climate change-related mitigation, adaptation and technology cooperation activities. On the lower end of the cost estimate, the World Bank (2008) estimates that up to $100 billion in mitigation and $30-70 billion in adaptation spending will be required in 2030, 80 percent of which will have to be financed by the private sector. At the high end of the estimate, the Stern Review (2006) suggests committing 1 percent of the global GDP, somewhere between $350 and $480 billion each year to cut GHG emissions. At the middle of the cost estimate, the United Nations Framework Convention on Climate Change report (UNFCCC 2007[b]) states that additional mitigation-related investment and financial flows of $200-210 billion as well as $20-30 billion in adaptation-related investment and financial flows would be necessary in 2030 just to return GHG emissions to current levels, with 86 percent of the investment and financial flows being generated from the private sector. (UNFCC 2007b).

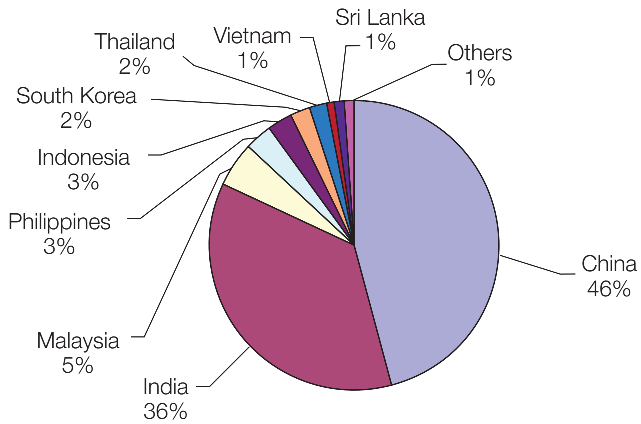
According to Asian Development Bank (2009) report, "Economics of Climate Change in Southeast Asia: A Regional Review", there are also growing number of regional and global financial (both private and public) resources to address climate adaptation and mitigation activities. However, these financial resources are likely to fall way short of what will be required to address climate adaptation and mitigation programs, activities, and projects in Southeast Asia.

2.2 Measuring the Global and Asian Climate Financial and Investment Flows

The global carbon market grew to \$64.0 billion in 2007, more than doubling the figure from 2006, according to a recent World Bank report (Capoor and Ambrosi 2008). The report also notes that the emissions allowance market, which consists of the Chicago Climate Exchange (\$72 million); New South Wales GHG Reduction Scheme (\$224 million); and the European Union Emission Trading Scheme (\$50.0 billion) also saw a doubling of both value (to \$50.3 billion) and number of allowances transacted (to 2,109) from the 2006 level. The global carbon market doubled or tripled in value for all segments (including secondary CDM, Joint Implementation, and other Compliance & Voluntary Transactions) except for projects in developing countries which saw a leveling off of market volumes transacted under the CDM — from 537 million tons of carbon dioxide equivalent (MtCO2e) in 2006 to 551 MtCO2e in 2007. \$9.5 billion was also invested in 2007 in 58 public and private funds that either purchase carbon directly or invest in projects and companies that can generate carbon assets, while CDM has been able to leverage \$33 billion in additional investment for clean energy.

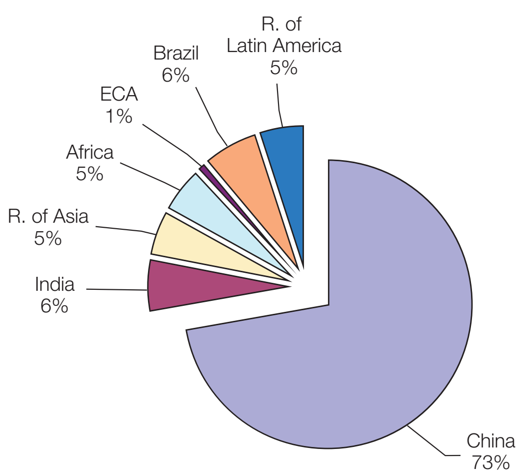
The emerging carbon market has resulted in financial and investment benefits for a number of Asian countries. China and India have been active as CDM project hosts, with China accounting for 46 percent and India 36 percent of all CDM projects in Asia (see figure 1). China accounted for 73 percent of all new CDM projects in 2007 (see figure 2). Worldwide, China, India, Brazil, and Mexico represent the market leaders with the four countries playing host to as much as 80 percent of all projects in recent years. In Asia, China, India, South Korea, and Vietnam are in the top five countries in terms of certified emission reduction (CER) credits received. The country that has arguably gained the most in terms of climate change-related financial and investment flow is South Korea, who received about 18 percent of all the CER credits worldwide so far and is currently the third largest recipient of CER credits, after China and India (see figure 3). Although China and India have more than 15 times the number of CDM projects in South Korea, these two countries only have twice as much CER credits as compared to South Korea. This is not likely to continue as most people expect South Korea to be re-classified as a “developed country” after 2012 (Forelle 2008).

FIGURE 1
CDM Projects in Asia by Country



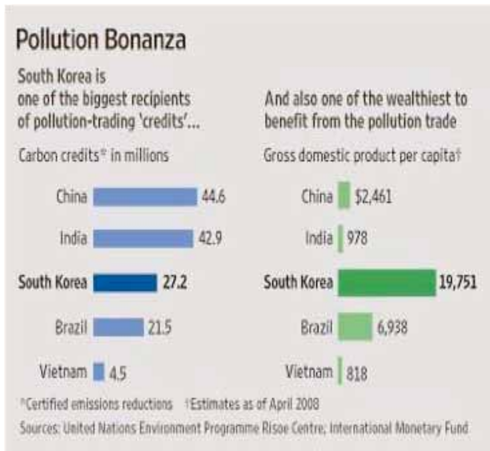
Source: UNEP Riso Centre 2008.

FIGURE 2
Location of CDM Projects in 2007



Source: World Bank 2008.

FIGURE 3
Asia and Certified Emissions Reduction (CER) Credits



Source: Charles Forelle 2008 "French Firm Cashes in Under UN Warming Plan, ***Wall Street Journal***, July 23, A1.

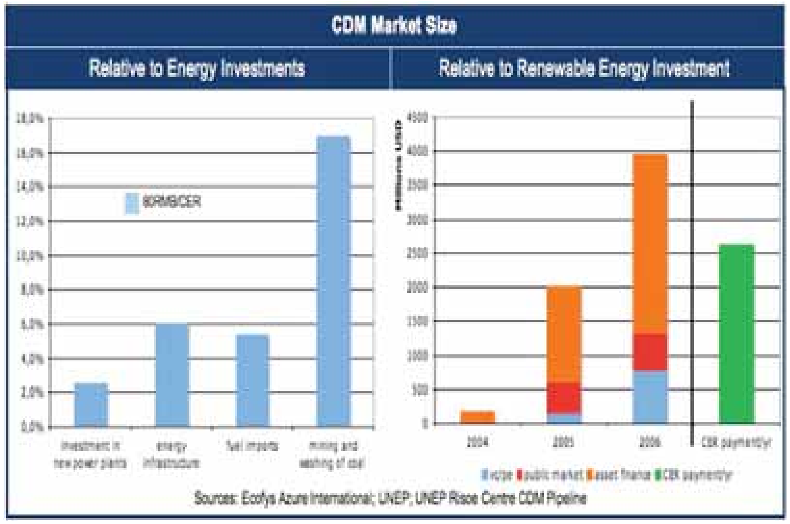
If South Korea has done surprisingly well in terms of garnering climate change-related financial and investment flows, China is the place where the future global carbon market is likely to be determined. Worldwide Fund for Nature (WWF) recently analyzed the CDM market in China and had the following conclusions (WWF 2008):

- The rapid rise of economic development and energy demand has reduced the potential environmental dividend of the increase in renewable energy and CDM growth in China (see figure 4). Given the dramatic increases of total domestic energy consumption, the overall environmental impact of renewable energy will be lower than what can otherwise be achieved.

- CDM can be useful tool for policy makers in steering the market towards achieving national policy objectives and CDM has played a significant role in supporting the growth of renewable energy sector, particularly in the wind sector.

- CDM contributed to improving market transparency and efficiency in renewable energy and industry sectors. Through formalizing project development actions both at the local level and at the international level, CDM has improved market transparency and the provision of reliable data in relevant sectors.

FIGURE 4
China and Clean Development Mechanism



Source: Worldwide Fund for Nature 2008.

The development of CDM and the voluntary carbon market is a positive market-based trend in addressing the climate change threat. But, it should be noted that the Kyoto Protocol and related market/policy mechanisms like CDM were designed to address climate mitigation, not adaptation (Keane and Potts 2008). Although it was agreed at the Bali Conference that a 2% levy can be placed on CDM transactions to fund an Adaptation Fund of some sort, it is not clear whether such a levy will generate enough funds that will become a basis of a sustainable funding mechanism. Moreover, institutionally, whether or not such a Fund will become a reality will depend on what kind of post-2012 climate change regime will be realized at the December 2009 UNFCCC conference in Denmark.

2.3 Challenge of Financing a Sustainable Asian Urban Future

Beyond what South Korea, China, and Asia as a region have received in terms of financial and investment flows through the global carbon market, additional financial and investment flows might be generated within Asia through Japan's $10 billion Cool Earth Partnership, which is expected to provide as much as $2 billion per year over the 2008-2012 time period (Porter et al. 2008). Asian Development

Bank's Energy Efficiency Initiative may be able to allocate as much as $1 billion in terms of new project financing, while the proposed carbon investment fund that is expected to finance around 40 carbon reduction projects (Minder 2008).

Given the scale of energy, environmental, and climate change challenges confronting Asia, it remains unclear what level of energy- and climate change-related financial and investment resources is going to be sufficient. Whatever the amount that will be required, the Asian urbanization process is likely to have a profound impact on both the amount and scope of the climate adaptation and mitigation activities. In 1960, Asia had only one megacity, defined as an urban center with a population with more than 10 million people or more. Today, there are over a dozen megacities in Asia. By 2015, 12 of the 22 megacities in the world are projected to be in Asia and by 2030, Asia will account for more than half of the world's urban population — 2.7 billion out of a total global urban population of 4.9 billion people (East-West Center 2009). According to the East-West Center (2009) report, "this shift in human living patterns produces new challenges in virtually every aspect of Asia's human organization".

U.S. Agency for International Development (2007) recently examined some of the most serious Asian energy, environmental, and climate change challenges and noted the following:

- Developing Asia currently accounts for about 23 percent of global CO2 emissions (6 million out of 26 million metric tons (Mt)), and its share of global emissions is projected to increase to nearly 50 percent (20 Mt out of 40 Mt) of global CO2 emissions by 2030.
- Coal use in developing Asia is projected to increase nearly four-fold during the period 2006-2030. Together, China and India are slated to consume 57 percent of the world's annual coal supply in 2030, up from 40 percent in 2004.
- If current trends continue, the increased demand for transportation will lead to a 2.6-fold increase in oil demand in developing Asia during this period, and a corresponding three-fold increase in CO2 emissions.

The key issue in determining whether the threat posed by climate change in the Asian context will persist, be dramatically worse, or improve is likely to be shaped whether or not the $6 trillion in new energy and other related infrastructure investments in China, India, Indonesia, Philippines, Thailand, and Vietnam, which account for 96 percent of the GDP in developing Asia, that will be made over the next two decades will be environmentally sustainable (UNFCCC 2007b).

2.4 Japanese Environmental and Energy Financial Innovation Case Study

Japan provides an excellent case study of how the different if not conflicting challenges of energy security, economic development, and environmental stewardship can be reconciled. From the early 1970s to the late 1980s, Japanese industry was suffering from oil boycotts and embargoes as well as a general slowing down of the world economy. Fortunately, there was broad consensus in Japan at that time that only a massive mobilization of energy efficient technologies and investments in resource productivity would save Japanese companies from an overdependence on oil imports and increase its industrial competitiveness (Hayashi 1990).

Although the overall level of capital expenditures dropped sharply as the result of the economic recession stemming from the 1973 oil shock, Japanese companies continued to place a high business priority on energy-efficient technologies. Between the late 1960s and the mid-1970s, the ratio of pollution prevention investments as a percentage of total capital expenditures increased from 3 percent to a high of 20 percent. While Japan's GDP grew 1.7 times from 1973 to 1987, its annual energy consumption level essentially remained flat, which means that the overall rate of energy consumption declined by more than 40 percent (Watanabe 1995).

The focus on energy efficiency and innovation has provided Japan with an important shield against unpredictable swings in the global energy market. The key component of its overall strategy is investing in energy efficient and environmental technology R&D, which has resulted in noteworthy economic dividends and efficiency gains. Japan on average consumes half as much energy per dollar worth of economic activity as the European Union or the United States, and one-eighth as much as China and India in 2005 (IEA 2008).

Japanese industry has managed to keep its overall annual energy consumption unchanged at the equivalent of a little more than a billion barrels of oil since the early 1970s, even as the economy doubled in size during the country's boom years of the 1970s and '80s. Japanese steel industry, for instance, invested about \$45 billion in developing energy-saving technologies between 1972 and 2006, or about \$1 billion annually for more than 30 years (Fackler 2008), while the Japanese government announced that it will inject about \$30 billion into the environmental and energy sector R&D will focus on R&D over the 2009-2013 time period (IEA 2008).

The key lesson from the Japanese experience in terms of energy-related financial and investment flows is that the importance of financing extends beyond just the disbursement of money. It has ultimately lead to the creation and development of a country or a region's capacity and knowledge for environmental and energy market innovation. To achieve the desired results, the increased financial and investment flows to address climate change need to be linked to a set of institutional structure and public policy which can facilitate and create business-led eco innovation. The increased flows will have to be completed by fiscal reforms that encourage innovation in renewable energy sources by decreasing the relative price of the use of renewable energy compared to fossil fuels, or by providing upstream tax incentives for private sector investments in R&D and capital investment (Johnstone and Hascic 2008).

3. MOVING TOWARD A NEW TRIPLE BOTTOM LINE STRATEGY OF FINANCING CLIMATE ADAPTATION AND MITIGATION ACTION IN ASIA

The socio-economically trans-nationalized character of environmental problems like climate change means that any global or regional solutions are going to present many problems, barriers, and most likely, a number of unintended consequences. Compounding the complexity of the problem is the challenge of making sure that any climate solution helps or at least does not hurt the poor, energy insecure, and economically marginalized groups in the region. How can the post-2012 Asian climate adaptation and mitigation strategy be economically efficient and market friendly and at the same time, be socially and environmentally equitable? Three issues and questions will be examined in the context of designing and building a new triple bottom line (economic, social, and environmental) strategy of financing climate change action in Asia.

3.1 Invest in a Sector-based Carbon Mitigation Strategy for Asian Industries

One of the more interesting developments arising from the increasing awareness of global climate change and the sharp rise in energy prices has been the growing awareness of concepts like 'carbon footprint' or 'food miles' (the distance travelled between farm to plate). In the business sector, with the assistance of groups like the carbon disclosure project and other similar initiatives, measuring, reducing, and managing the carbon footprint of industries has become an important business priority.

Of course, not all industries have the same level and scope of carbon footprint concerns. It is estimated that the commercial and residential building sector in the U.S. consume 65% of all electricity generated, 12% of fresh water supplies, 40% of all raw materials, as well as contribute to about 33% of all greenhouse gas emissions. Even in a newly industrializing country like Mexico, the building sector consumes 25% of all electricity generated and contributes to about 20% of greenhouse gas emissions (CEC, 2008). In the case of China, two billion square

meters are constructed; about 50 percent of the floor space built worldwide. Consequently, the China's building sector represents not only an important regional as well as global climate mitigation challenge (GDI 2008).

For the developing Asia region, it is important to acknowledge the uncertainty and complexity of quantifying and assessing the economic impact of putting a price tag on carbon, and this will be of particular importance to electric utilities and other companies in energy-intensive sectors in developing Asia, as they are significantly more carbon intensive compared to Japan/OECD advanced industrialized countries. For instance, a Japanese electric utility produces on average only a third of the carbon emissions per unit of electricity as compared to a typical Chinese electric utility.

In terms of social equity considerations, any attempt to lower the carbon intensity and/or reduce energy consumption through the introduction of a carbon tax and/or cutting the fuel subsidy is likely to impact (at least on the short-term) the poor/economically marginalized population through increased prices and/or transitional costs. Reducing the various fuel subsidies in Asian countries will reduce the market distortion such subsidies are causing the market and improve the market acceptability of more environmentally-friendly energy options. However, additional policy measures may be necessary to minimize the short-term economic impact on the poor.

3.2 Finance Community-based Ecosystem and Clean Energy Micro-Enterprises

SMEs (small and medium-sized enterprises) represent the dominant form of business organization worldwide, accounting for more than 90-95 percent of the business enterprises worldwide depending on the country or the region. Most critically in terms of market development, SMEs can have a multiplier effect on the economy by accelerating employment, raising incomes, and helping build new products, services, and business models that fundamentally alter an industry (Yago, Roveda, and White 2007).

Despite the surge in the popularity of the micro-credit/enterprise model worldwide, SMEs remain underserved by financial markets in emerging and developing economies. Weak business climates as well as an underdeveloped financial system severely limit SME business development in industrialized (most notably in Japan) and developing Asia. If these SMEs are unable to raise capital to take advantage of new opportunities to design new products and services, then small firms are less likely to become bigger and more successful companies (Yago, Roveda, and White 2007).

This is what many development experts refer to the "missing middle" dilemma, where SMEs are caught in the middle of the business financing cycle where they are too large to cater to micro-credit/enterprise financing and too small and unstable in terms of cash flow to attract financing from commercial banks. Microsoft, Ebay, and Google were all once SMEs in the U.S. and received many rounds of venture capital and other financing before becoming a world-renown multinational business enterprise.

The high financial inflexibility and low business scalability have been traditionally regarded just as economic development issues, but they are also emerging as critically important environmental and social concerns. According to the World Resources Institute (2008), forestry, fishing, farming and other types of ecological extractive activities can be the basis of a powerful model for ecosystem- as well as renewable energy-based business enterprise that delivers continuing economic and social benefits to the poor, even as it improves the natural resource base.

Helping the poor to increase their environmental income through good resource stewardship and competent business models can contribute to reducing rural poverty and building more resilient rural communities that can better withstand the complex environmental and economic challenges posed by climate change. Without adequate financial and organizational resources, coupled with necessary land tenure and other policy reforms, these rural communities will not be able to effectively engage their local, national, and even international markets.

The development of these ecosystem-oriented micro-enterprises is a critical one for developing Asia because nearly 90% of poverty occurs in rural areas, which is even higher than the global rate of 76%. Moreover, the vast majority of the about 2.4 billion people in developing countries that lack access to clean and reliable sources of energy live in the Asian and Pacific region. To meet the basic cooking needs of these 2.4 billion people, it is estimated that no more than 1% of the current global commercial energy consumption is required, while financially viable and technologically feasible off-grid electricity sources are currently available to households and business enterprises. Increased use of efficient and renewable systems improve energy security of the Asian rural communities by avoiding excessive dependence on imported fuels, developing local sources and diversifying energy portfolios and suppliers (UNESCAP 2005).

While the need is greater than the supply, there are a number of social/environmental investment funds and business development technical assistance providers in the U.S. (e.g. the New Jersey-based E+Co that work on sustainable energy issues, and Cambridge, Massachusetts-based Root Capital that help support biodiversity-oriented business enterprises) and Europe that provide support for Asian energy and social micro-enterprises like Desi Power (India), Solar Electric (Philippines), Lotus Energy (Nepal).

3.3 Build Climate Resilience Through a Market-Based Adaptation Strategy

The insurance/financial industry is specifically mentioned in the UNFCC as a possible tool to address climate change. Article 4.8 of the Framework Convention requires all Convention Parties to fully consider actions, including actions related to insurance, to meet the specific needs and concerns of developing countries with respect to the adverse impacts of climate change. While the bulk of the weather-related insurance losses occur in the wealthy industrialized countries, most of the human suffering occurs in the poor developing countries. Between 1985 and 1999, the wealthy countries accounted for 57 percent of the $984 billion in total economic losses and 92 percent of the $178 billion in insured losses whereas only 25 percent of the economic losses and 65 percent of the 587,000 deaths took place in the poorest countries.

There are a number of reasons why the poor in Asia and in other regions/countries remain vulnerable to climate change-related natural disaster risks. First, the poor often live in areas especially vulnerable to destructive events such floods, hurricanes, and landslides. Second, disasters can severely depress the food production of the rural poor. Third, even small reductions in income can have a dramatic impact on the poor. The poor are unlikely to have enough savings to withstand the economic shocks of large-scale or multiple catastrophes. Fourth, damage to water supply and transport infrastructure hurt the poor more than they hurt the wealthy (Freeman and Muthukumara 2003).

There are a number of emerging market-based adaptation instruments to address weather and climate disaster type risks including: catastrophe bonds; contingent surplus notes; exchange-traded catastrophe options; catastrophe swaps; and weather derivatives. Case in point : Commonwealth and Smaller State Disaster Management Scheme was established in 2002 to provide affordable insurance so that the outstanding public sector loans can be continued to serviced for up to three years following natural disasters. Payouts are triggered by extreme weather events based on independently verified meteorological data. Based on preliminary studies undertaken in Ethiopia, Morocco, Nicaragua, and Tunisia, the World Bank is investigating the possibility of providing weather index insurance for the agricultural sector, in which a new insurance plan will pay out for extreme weather events (e.g. where rainfall is dramatically lower than the regional average), as opposed to waiting for a full blown humanitarian crisis to develop before disbursing development assistance.

One promising (though untested) market-based climate adaptation tool is the catastrophe bond market, which was developed after Hurricane Andrew devastated the insurance industry in 1992. Most of the bonds are intended to protect insurers from disasters that happen once or maybe twice in a century, so they will not be applicable to natural disasters that happen frequently like flooding due to monsoons. In exchange for relatively high interest rates between 5 to 15 percent, which makes them attractive to many institutional investors, the poor in developing Asia and elsewhere may be able to tap into the international bond market to get some economic compensation from natural disasters.

4. MAINSTREAMING MARKET-BASED CLIMATE ADAPTATION AND MITIGATION STRATEGY IN URBANIZING ASIA

Until very recently, few business strategies for even private companies to protect themselves against a wide range of weather-related market risks. This is surprising given that nearly 20 percent of the U.S. economy is directly affected by the weather, and the business outlook for some of the world's largest industries — energy, travel, agriculture, entertainment, and others — are subject to uncertain weather fluctuations and disturbances. Business insurance typically provided protection against catastrophic damages and did little to nothing to protect companies from a downturn in business as the result of unexpected weather warming or cooling.

It was until the 1990s that people began to realize that it might be possible to package and trade weather like a commodity if they could quantify and index weather patterns in terms of monthly or seasonal average temperatures and attach a dollar amount to each index value. For instance, a ski resort might purchase a weather derivative to protect itself against an unexpected downturn in the amount of snowfall. The concept of weather as a tradable commodity was officially launched as the first weather derivative trade took place in the Chicago Mercantile Exchange in 1997 and the current market for weather derivatives may be approaching close to $10 billion.

Unfortunately for the 2.4 billion people in Asia and elsewhere around the world that lack access to clean and reliable sources of energy, there are little to no government disaster relief programs and/or government/private insurance schemes to protect them against natural disasters and other environmental/public health risk factors that are bound to intensify with global climate change. While trying to put in place global and regional policies to mitigate greenhouse gas emissions, an important business, if not an ethical, case can be made for an effective and equitable climate adaptation solutions so that the economic, social, and environmental consequences of a warming planet do not fall disproportionately on the global poor.

References

Asian Development Bank. 2009. *The Economics of Climate Change in Southeast Asia : A Regional Review* Manila: ADB.

Barber, T. 2009 "EU Proposes Rich Nations Give upto €50 bn a year in Climate Fight." Financial Times, October 31/November 1: 1

Capoor, K., and Ambrosi, P. 2008. *State and Trends of the Carbon Market 2008.* Washington DC: World Bank Institute.

CEC (Commission on Environmental Cooperation). 2008. *Green Building in North America: Opportunities and Challenges.* Montreal: CEC.

East-West Center. 2009 *The Urban Transformation in Asia : Policy Implications of Decentralization.* Honolulu, Hawaii: East-West Center.

Fackler, M. 2008. "Japan Sees a Chance to Promote Its Energy-Frugal Ways." New York Times, July 4.

Forelle, C. 2008. "French Firm Cashes in Under UN Warming Plan." *Wall Street Journal* 23 (July): A1.

Freeman, P. Keen. M., and Muthukumara M. 2003. "Being Prepared." Finance & Development, September: 43.

GDI (German Development Institute). 2008. *Energy Efficiency in Buildings in China Policies, Barriers and Opportunities.* Bonn: GDI.

Hayashi, T. 1990. *The Japanese Experience in Technology: From Transfer to Self-Reliance*. Tokyo: United Nations University Press.

IEA (International Energy Agency). 2008. *Energy Policies of IEA Countries – Japan*. Paris: IEA

Johnstone, N., and Hascic I. 2008. "Eco-innovation, Policy and Globalisation." OECD Observer, December/January: 15–16.

Keane, J., and Potts G. 2008. "Achieving Green Growth in a Carbon Constrained World." ODI Background Note, October, Overseas Development Institute, London.

Minder, R. 2008. "ADB Plan to Buy Carbon Credits after 2012." Financial Times, July 7.

Nakhooda, S. 2008. "Correcting the World's Greatest Market Failure: Climate Change and the Multilateral Development Banks." WRI Issue Brief, World Resources Institute, Washington, DC.

Oxfam. 2009. *The Right to Survive: The Humanitarian Challenge for the 21st Century.* London, UK: Oxfam.

Porter, G., Bird N. Kaur N., and Peskett L. 2008. *New Finance for Climate Change and Environment.* Washington DC: WWF and Heinrich Boll Foundation.

Stern, N. 2006. *Stern Review: The Economics of Climate Change*. Cambridge, UK: Cambridge University Press.

UNESCAP (UN Economic and Social Commission for Asia and the Pacific). 2005. *Energy Services for Sustainable Development in Rural Areas n Asia and Pacific*. Policy and Practice Energy Resources Development Series 40. Bangkok: UNESCAP.

UNFCCC (United Nations Framework Convention on Climate Change). 2007a. *Bali Action Plan*. Bonn: UNFCCC. http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf#page=3.

_____. 2007b. *Investment and Financial Flows to Address Climate Change*. http://unfccc.int/cooperation_and_support/financial_mechanism/items/4053.php.

US Agency for International Development. 2007. *From Ideas to Action: Clean Energy Solutions for Asia to Address Climate Change.* Bangkok: US AID. http://usaid.eco-asia.org/programs/cdcp/report.html.

Watanabe, C. 1995. "The Interaction Between Technology and Economy: National Strategies for Constrained Economic Environments: The Case of Japan 1955-1992." IIASA Working Paper 95, February 16.

World Bank. 2008. *Towards a Strategic Framework on Climate Change and Development for the World Bank Group.* Washington DC: World Bank. http://go.worldbank.org/6HVS12Q5M0.

Worldwide Fund for Nature. 2008. *Value of Carbon in China*. Hong Kong: WWF.
http://wwf.org.hk/eng/pdf/references/pressreleases_hongkong/WWFcarbon_report_FINAL_20080630_ENG.pdf.

World Resources Institute, UNDP (UN Development Program), UNEP (UN Environment Program), and the World Bank. 2008. *World Resources Report: Roots of Resilience.* Washington DC: World Resources Institute.

Yago, G., Roveda D., and White J. 2007. *Transatlantic Innovations in Affordable Capital for Small and Medium-Sized Enterprises: Prospects for Market-based Development Finance.* Washington DC: German Marshall Fund of the US.

CHAPTER 26

The Price of Climate: French Consumer Preferences Reveal Spatial and Individual Inequalities

Jean Cavailhès,* Daniel Joly, Hervé Cardot, Mohamed Hilal, Thierry Brossard, Pierre Wavresky

Summary

We use the hedonic price method to study consumer preferences for climate (temperature, very hot or cold days, and rainfall) in France, a temperate country with varied climates. Data are for (i) individual attributes and prices of houses and workers and (ii) climate attributes interpolated from weather stations. We show that French households value warmer temperatures while very hot days are a nuisance. Such climatic amenities are attributes of consumers' utility function; nevertheless, global warming assessments by economists, such as the Stern Review Report (2006), ignore these climatic preferences. The social welfare assessment is changed when the direct consumption of climate is taken into account: from the estimated hedonic prices, we calculate that GDP rises by about 1% for a 1°C rise in temperature. Moreover, heterogeneity of housing and households is a source of major differences in the individual effects of climatic warming.

*Corresponding author: jean.cavailhes@dijon.inra.fr

1. INTRODUCTION

We investigate the hedonic prices of climate in France.[1] First, we show that climate change impacts GDP through the capitalization of such prices in land rents and/or wages; this cannot be ignored, then, when assessing the macroeconomic effects of warming. Second, in France, people are not equal when it comes to warming: inequalities appear between individuals depending on their location (the elderly migrate to sunnier climates) or their preferences (owner-occupiers of single detached houses are more sensitive to climate than tenants of apartments).

Consumers' climatic preferences are ignored in the global warming debate. Yet there are grounds for believing that, in their private behavior, inhabitants of temperate countries put a positive value on warmer temperatures, while very hot or very cold days are a nuisance: empirical studies converge toward these two findings. Such climatic amenities and nuisances are attributes of consumers' utility functions. Several consequences follow from this.

First, at the macroeconomic level, allowing for the value of these attributes modifies economic welfare. In particular, the non-egalitarian effects of global warming might be greater than the effects sometimes estimated (see Stern et al. 2006): inhabitants of temperate countries (e.g. France, U.K.), where the mean temperature will rise, will see their welfare increase whereas inhabitants of hot countries (e.g. Mexico, Egypt), where heatwaves will be more marked, will see their welfare decline. These direct effects must be taken into account in global warming assessment, otherwise the international climate negotiations would be distorted.

Second, at the microeconomic level, the contradiction between private optimum and social optimum might be greater than in the standard case (congestion, pollution, etc.) because, as global warming improves the private optimum of consumers in temperate countries while diminishing the global social optimum, the two effects have opposite signs. It will therefore be more difficult to get citizens in temperate countries, which are big producers of greenhouse gases, to accept public policies combating global warming. These private effects must be taken into account in public announcements and campaigns to heighten awareness of the hazards of warming. Otherwise, such talk would be given little credence by people who feel an improvement in their own private welfare.

Thirdly, individuals are not equally affected by warming. Warming does not have the same effect for someone in an apartment or in a detached house, or for someone in the city or in the country. The elderly and the young do not have the same demand for climatic goods. This diversified behavior must also be taken into account in policies for combating warming or they shall not attain their targets.

---

[1]This research was financed by the French *Ministère de l'Emploi, de la Cohésion sociale et du Logement*. It uses data from Housing Surveys by the *Institut national de la statistique et des études économiques* (INSEE).

Here we study consumer preferences for climate (mean annual temperatures, mean January and July temperatures, summer heatwaves, coldest winter days, annual and monthly rainfall) in France. We use the hedonic price method (Rosen 1974) to determine the price of climatic attributes, which are capitalized in wages and/or land rents. This enables us to assess the increase in welfare brought about by a rise in temperatures. We use individual data from housing surveys by the French National Institute for Statistics and Economic Studies (INSEE). Econometric estimates are made on real-estate values (owner-occupiers and tenants) and on wage-earners. Climatic variables are required for the entire country to be matched with these data. They are obtained by interpolation by local regression and kriging of readings from weather stations.

Section 2 summarizes the economic literature on climate and presents the micro-economic analysis. The econometric models, economic and climatic data are covered in Section 3. The results are presented and discussed in Section 4. Section 5 concludes.

2. CLIMATE IN ECONOMICS

2.1 The Hedonic Price of Climate

To the best of our knowledge, estimations of the hedonic price of climate date back to Hoch and Drake (1974). Prominent work was done in the domain by Cragg and Kahn (1997; 1999). In many other studies since Henderson (1982), climatic attributes are variables selected to measure among other things the quality of life or to control for spatial heterogeneity (e.g. Blomquist et al. 1988). Recently, debate about climate change has led to examination of the effects of climate on welfare at a global scale (Maddison 2003; Rehdanz and Maddison 2005). The effect of climate on population migrations also has a long history (Graves 1976; 1980; Graves and Linneman 1979). Cheshire and Magrini (2006) have recently shown the impact of climate on the growth of urban populations in Europe.

The findings show that January and July temperatures command significant hedonic prices (capitalization in wages is negative for winter and positive for summer), as is generally the case with rainfall, wind speed, and hours of sunshine. In the U.S., a variation of one standard deviation in any one of these attributes accounts for 2% to 3% of wages.

Little work has been done in Europe. In a study of Italy, Maddison and Bigano (2003) conclude that July temperatures and January rainfall have a negative effect on welfare and that the number of days of clear skies has a significant effect in Milan. Maddison (2001) shows that mean annual temperatures and rainfall are significant in a housing-price function in the U.K. Rehdanz and Maddison (2008) show that German households prefer warmer winters with less rainfall. It should be noted that such research is seldom conducted on individual data, so there is no way of telling whether or not the results are sensitive to the characteristics of housing or households.

2.2 Economic Valuation of Climatic Warming

Nordhaus (1991; 1992) pioneered the economic valuation of warming by developing climatic-economic models, which were rapidly followed by others. The Stern Review Report (Stern et al. 2006) also relies on a climatic-economic model (Hope 2006). Time is at the core of these studies, whether for very long-term climatic changes or for inter-temporal economic reasoning. The aim is to compare the damage and prevention costs so as to find an optimal policy pathway for reducing greenhouse-gas emissions.

The conclusions broadly converged until recently: emission-reducing policies are required and the optimal pace is to implement them slowly today, and then intensify them progressively over time. The Stern Review (Stern et al. 2006) conclusions are the other way around: highly restrictive measures should be taken immediately. The crux of the divergence is the discount rate. We shall steer clear of this debate. The divergence also relates to the economic agents' capacity to adapt (Mendelsohn et al. 1994).

2.3 Welfare

Climate, which is an attribute of the consumer utility function, must be allowed for when calculating social welfare, regardless of the indirect market costs and benefits generally used in cost-benefit analysis of warming. In this way, the two strands of the literature just discussed can be unified.

Rosen (1979) and Roback (1982) provide foundations for the reasoning, which are summarized by Gyourko et al. (1999) in this way. Let the program of a consumer j at location k be: $\max U = U(Z_j, S_j, A_k, \alpha_j)$, under the constraint: $Z_j + R_k S_j, W_k$, where Z is an aspatial composite good (taken as the numeraire), R is the land rent, S the area of a residential lot, A a climatic amenity, W income, and α_j are characteristics specific to consumer j. The indirect utility function V is $V_{jk} = V_j(W_k, R_k, A_k)$, and at the optimum: $V^* = V_{jk}$.

Let also a firm's profit be:

$$\pi_{jk} = pY_j(M_j, L_j, S_j, A_j, \beta_j) - p_M M_j - W_k L_j - R_k S_j$$

where Y is output and p its price, M is capital input and p_M its price, L labor, S

land, and β_j are characteristics of firm *j*. The indirect profit function is: $\Pi_{jk} = \Pi_j(W_k, R_k, p, p_M, A_k)$, and at the optimum $\Pi^* = \Pi_k$.

Wages and rents at equilibrium are determined from the utility and profit functions. From the first order conditions, it is easy to obtain the variations in wages and rents with amenities (indexes denote partial derivatives), which are:

$$\frac{\partial W}{\partial A} = \frac{\frac{1}{V_W}\left(-V_A + V_R \frac{\Pi_A}{\Pi_R}\right)}{1 - \frac{V_W}{V_R}\frac{\Pi_R}{\Pi_W}} \text{ (indeterminate sign) and } \frac{\partial R}{\partial A} = \frac{-\frac{V_A}{V_R} + \frac{V_W}{V_R}\frac{\Pi_A}{\Pi_W}}{1 - \frac{V_W}{V_R}\frac{\Pi_R}{\Pi_W}} > 0 \quad (1)$$

Land values rise with amenities. The sign is indeterminate for wages: if the amenity does not affect firms' productivity (P_A=0), the amenity is negatively capitalized in wages. If the amenity has positive productivity, the change in wages is indeterminate, and rents increase more than in the previous case.

If warming is an amenity in temperate countries, an increase in temperature *ceteris paribus* entails an increase in consumer's utility because consumers enjoy a greater quantity of this good. To maintain their utility at the same level the government has to collect a tax, which swells the public purse. Otherwise, tenants pay more (cf. (1)) and landowners receive more rent, which is imputed to the households item in the National Accounts. In both cases, the climatic amenity is reflected by a gain in GDP brought about by warming.

This effect depends on consumer preferences and firms' technology levels, on assumptions about international trade, and on the initial level of temperature: all things been equal, GDP will rise in a temperate country, which is sensitive to warming, and will decrease in a hot country, which is negatively affected.

3. METHODS AND DATA

3.1 Econometric Issues

First, the identification problem is well-known in hedonic literature: the second step of Rosen's method (1974) is required to estimate the supply and demand functions (see especially Brown and Rosen, 1982), except if supply is price-inelastic (Freeman, 1979), which is the case of climate attributes.

Second, some explanatory variables may be endogenous (Epple 1987), particularly in a housing equation, when the purchaser simultaneously chooses the price (dependent variable) and the quantity of certain attributes (e.g. the living space). Thus, we use the instrumental method, using personal characteristics of the households as instruments, as theory suggests (Epple 1987). Their exogeneity is tested by Sargan's method, and the endogeneity of the covariate(s) is tested by Hausman's method. The main equation is then estimated by the 2SLS.

Thirdly, there are many and strong correlations among climatic variables. If multicollinearity occurs (detected by the *condition number*), we use a second estimation procedure, Partial Least Squares (PLS) (Wold 1985), which may be thought of as an intermediate procedure between OLS and principal component regression (Stone and Brooks 1990). We used a modified version of this algorithm (Bastien et al. 2005), and a bootstrap approach to determine the distribution of the PLS estimators of regression coefficients, and to calculate mean confidence intervals. Finally, the spatial autocorrelation between the residuals cannot be tested because the data are anonymous: their spatial distribution is unknown.

3.2 The Economic Data

The economic data are mainly from housing surveys conducted by the INSEE. The climatic variables and the spatial variables (see below) were matched with these surveys by the INSEE.[2]

The Mincer-type wage equation (Mincer 1962) was obtained from individual income data of people in dwellings surveyed in 2002. After excluding state employees and extreme wages, the sample comprised 19,063 people. The endogenous variable is the logarithm of the annual wage earned in the 12 months preceding the survey. The explanatory variables are: age, sex, socio-occupational category, employment rate, employment contract type, highest diploma, nationality, and country of birth.

For housing, we selected households that had moved in recently (within the last four years). Four equations were estimated for buyers and tenants crossed with detached houses and apartments. We had a total of 9,640 buyers of single-detached houses, 2,658 buyers of apartments, 3,447 tenants of single-detached houses and 8,615 tenants of apartments. The data were deflated into 2002 euros. The explanatory variables are: detached housing or housing in apartment blocks, survey year, floor space, garden area for detached houses (quadratic form), sanitation facilities (bathrooms and toilets), main room size (quadratic form), heating type, garage, parking space, cellar, veranda, fireplace(s), date of construction of the structure (quadratic form), and the date the household moved in.

[2]We thank Alain Jacquot and Anne Laferrère for authorizing this operation when they were heads of the Housing Division.

Spatial variables were also introduced into the equations (see Appendix 2).[3] Lastly, variables characterizing the climate were introduced into each of these equations.

3.3 Climatic Data

Climatic variables come from Météo-France (monthly data for the period 1970–2000). They are: mean annual temperature, temperatures for January and July, number of days with temperatures of less than –5 °C in January and more than 30 °C in July, mean monthly rainfall, rainfall in January and July, number of days' precipitation in January and July.

These data are recorded by a network of scattered weather stations. Interpolation is used to reconstruct a spatial continuum based on this information (Joly et al. 2011). First we use regressions between temperature/rainfall and explanatory variables suggested by climatology,[4] and then kriging of residuals from the regressions. As the models and parameters estimated are not identical over an area of the size of France, interpolation is done for small polygons including the 30 closest stations. The predicted values are computed for each French commune, and then merged with the housing survey data.

4. RESULTS

We do not comment here on the results of the non-climatic characteristics as they are not the relevant variables in this paper. Table 1 shows the results of climatic variables.

For the housing equations, we tested whether the living space was endogenous (because of a simultaneous choice between the size of the housing and its price). The results show that it is endogenous in three out of four equations (it is exogenous for owner-occupied of single-detached houses); in this case its projection is used in the main equations, estimated by 2SLS or by PLS.

The *condition number* diagnostic shows that multicollinearity occurs between climatic variables anyway; it is average-sized despite the high Pearson's corre-

---

[3]Urban areas comprise an urban center (urban units with 5000 jobs or more) and a periurban belt (communes where 40% of active residents commute to work outside the commune but within the urban area). The delimitation method is similar to that for *Statistical Metropolitan Areas* in the US but the thresholds are lower.

[4]A GIS was made up of climatic data, geographical coordinates of the weather stations and a set of explanatory variables used in regression, made up from two information sources: a land-use image from the Corine Land Cover (CLC) European database and a digital elevation model (DEM) produced by France's *Institut géographique national* (IGN). Eleven explanatory variables are produced: latitude and longitude, a vegetation index, the distance to the nearest forest, to the nearest sea or ocean, slope angle, slope orientation, topographic ruggedness, prominence index, and aggregate theoretical radiation for the summer solstice. Temperature and rainfall are explained by the best covariates.

lation coefficients. Therefore, the PLS estimation was made in any case. In most of the equations, the results are similar to those of the OLS/2SLS, confirming that multicollinearity does not affect the estimates too much (probably because of the high number of observations). From the equation and the estimation method, the R^2 varies between 0.54 and 0.61.

4.1 Hedonic Price of Temperature and Rainfall

The first finding shown by Table 1 is the lack of significance of the estimates in the wage equation (the number of January days with rainfall is an exception, with an unexpected negative sign). In France, climatic amenities are not capitalized in wages. This is probably because wages are often independent of location (and so insensitive to climatic amenities), due to labor-market regulations at the national level. Afterwards, we focus on the real-estate findings.

The mean annual temperature has a positive significant effect on the housing price for owner-occupiers: a rise of 1 °C entails an increase in housing prices of 5.9–6.2% (according to the equation and estimation method). The sign is also positive for tenants, with values between 2.5 and 3.9%, which are roughly half as much as for owner-occupiers.

The effect of warmer summers (mean July temperature minus mean annual temperature) is compounded with the preceding one for single-detached houses: an extra 1 °C entails a price increase of 3.7 to 8.4% (depending on the model). This effect is insignificant for apartments. Hot summer days (more than 30 °C) have a significant effect for owner-occupiers of single-detached houses and renters of apartments. At the median point, an extra day of heat lowers the value of housing by 4.3% (owner-occupiers) or by 1% (tenants). This effect is quadratic, probably due to seaside sites where hot summers are appreciated. French households are insensitive to cold winters, either the January temperature minus the mean annual temperature or the number of coldest days (less than – 5 °C). These influences may be unimportant because it is easy to protect oneself both by heating and by winter clothes.

The number of days' rain in January and July has a significant effect on real-estate values. The January sign is the expected: prices or rents fall by almost 1.2–2.3% for an extra day's rain. The number of days of rainfall in July also exerts a positive effect on the price of apartments (but not on the price of single-detached houses), indicating that households pay more for their housing (1.4 to 4.4%) for an extra summer day's rain.

TABLE 1
Results: Climactic Variables

	owner-occupiers							
	single detached houses				apartments			
	OLS		PLS		2SLS		PLS	
	estimate	Pr > |t|	estimate	p value	estimate	Pr > |t|	estimate	p value
Mean annual temperature (°C)	0.0599	<.0001	0.05726	<.0001	0.057262	0.0074	0.05812	0.009
Difference (July-mean annual temperature) (°C)	0.08037	0.0004	0.06848	0.001	0.063547	0.2275	0.04482	0.135
Difference (January-mean annual temperature) (°C)	0.02591	0.1814	0.01459	0.37	0.046843	0.2858	0.01777	0.359
July warm days (> 30° C)	-0.04199	<.0001	-0.0405	<.0001	-0.01963	0.2092	-0.02498	0.109
(July warm days)² (> 30° C)	0.00149	<.0001	0.001424	<.0001	0.001413	0.0481	0.001596	0.031
January cold days (< - 5° C)	0.00669	0.4935	0.0009078	0.476	-0.01368	0.5215	-0.01974	0.229
(January cold days)² (< - 5° C)	0.0014	0.0504	0.001858	0.011	0.00268	0.1034	0.002955	0.054
July days with rainfall	0.00948	0.0723	0.007804	0.088	0.042811	0.0001	0.03886	<.0001
January days with rainfall	-0.02237	<.0001	-0.02203	<.0001	-0.01444	0.076	-0.01427	0.057

	Tenants							
	single detached houses				apartments			
	2SLS		PLS		2SLS		PLS	
	estimate	Pr > |t|	estimate	p value	estimate	Pr > |t|	estimate	p value
Mean annual temperature (°C)	0.037957	0.0162	0.03737	0.005	0.027625	0.0005	0.02504	0.004
Difference (July-mean annual temperature) (°C)	0.062578	0.0678	0.03617	0.022	-0.00171	0.9285	-0.002226	0.453
Difference (January-mean annual temperature) (°C)	0.033658	0.2703	0.005734	0.411	-0.0109	0.5144	-0.015	0.081
July warm days (> 30° C)	-0.00714	0.4654	-0.01138	0.115	-0.02554	<.0001	-0.02361	0.001
(July warm days)² (> 30° C)	0.000237	0.4755	0.0002927	0.184	0.001056	<.0001	0.0009637	0.001
January cold days (< - 5° C)	-0.02078	0.1754	-0.02962	0.045	-0.00454	0.6019	-0.008856	0.218
(January cold days)² (< - 5° C)	0.003287	0.006	0.004102	0.001	0.000299	0.6781	0.0005114	0.308
July days with rainfall	0.008452	0.3083	-0.001103	0.443	0.013582	0.0011	0.01394	0.002
January days with rainfall	-0.01335	0.0205	-0.01225	0.022	-0.02014	<.0001	-0.01987	<.0001

	wages			
	OLS		PLS	
	estimate	Pr > |t|	estimate	p value
Mean annual temperature (°C)	0.00245	0.7347	0.001933	0.395
Difference (July-mean annual temperature) (°C)	-0.01279	0.5443	-0.002569	0.461
Difference (January-mean annual temperature) (°C)	-0.02325	0.2086	-0.01892	0.136
July warm days (> 30° C)	-0.00185	0.4407	-0.002552	0.176
(July warm days)² (> 30° C)				
January cold days (< - 5° C)	-0.00053069	0.8947	-0.00178	0.349
(January cold days)² (< - 5° C)				
July days with rainfall	0.00531	0.2469	0.005169	0.127
January days with rainfall	-0.00819	0.0112	-0.007652	0.011

Source: Authors' results.

4.2 Does France Benefit from Warming?

It would be beyond the scope of this paper to propose a scenario of climate change and to assess its effects on French GDP. We propose something less ambitious here: to show that direct consumption of climate and its capitalization in rents and/or wages have a significant macroeconomic effect.

Let us set out some simplifying assumptions: (i) in France, the capitalization of the price of climate into wages can be ignored; (ii) the land and structure combination in the housing production function is assumed to be constant, which is an acceptable hypothesis, since the housing stock in France is renewed slowly; (iii) land consumption by firms is ignored; (iv) housing and workers are internationally immobile. It follows that warming does not impact on production; the price of warming is capitalized only in the land rent. French consumers' utility increases, owing to the greater quantity of temperature, entailing a real increase in wealth. GDP therefore rises in real terms. We also assume there is neither redistribution nor are there indirect effects, and we ignore the regional effects within France (migrations, etc.).

By way of illustration, we study the effects of a rise of the mean temperature by 1 °C from 11.8 °C to 12.8 °C. We assume the rise in temperature is uniform nationwide. July temperatures, and July days of more than 30 °C (if significant) are changed when mean annual temperature rises, in accordance with the elasticity

TABLE 2
Effect of a 1 °C mean Annual Temperature Rise on Housing Prices and GDP

	owner-occupiers				tenants			
	single detached houses		apartments		single detached houses		apartments	
	OLS	PLS	2SLS	PLS	2SLS	PLS	2SLS	PLS
Mean annual temperature (°C) (€)	1008.8	963.0	920.3	934.5	2.67	2.63	1.79	1.62
Difference (July-mean annual temperature) (°C) (€)	1367.6	1158.3	NS	NS	4.47	2.55	NS	NS
July warm days (> 30° C) (€)	-763.0	-738.9	NS	NS	NS	NS	-1.85	-1.71
TOTAL (€)	1613.3	1382.4	920.3	934.5	7.14	5.18	-0.07	-0.09
TOTAL (%)	9.9%	8.5%	5.9%	6.0%	10.3%	7.5%	-0.1	-0.14

NS: unsignificant

global effect on GDP	1.0%	0.8%

	single detached houses		apartments	
	OLS	PLS	2SLS	PLS
	owner-occupiers			
Mean annual temperature (°C) (€)	1008.8	963.0	920.3	934.5
Difference (July-mean annual temperature) (°C) (€)	1367.6	1158.3	NS	NS
July warm days (> 30° C) (€)	-763.0	-738.9	NS	NS
TOTAL (€)	1613.3	1382.4	920.3	934.5
TOTAL (%)	9.9%	8.5%	5.9%	6.0%
	tenants			
Mean annual temperature (°C) (€)	2.67	2.63	1.79	1.62
Difference (July-mean annual temperature) (°C) (€)	4.47	2.55	NS	NS
July warm days (> 30° C) (€)	NS	NS	-1.85	-1.71
TOTAL (€)	7.14	5.18	-0.07	-0.09
TOTAL (%)	10.3%	7.5%	-0.1	-0.14

NS: unsignificant

global effect on GDP	1.0%	0.8%

Source: Authors' results.

between these variables. We ignore the effects of warming on rainfall, and the effects on temperature for months other than July. Table 2 shows the results.

The effects on housing prices are sizeable for single-detached houses (9% or so), weaker for owner-occupiers of apartments (6%) and negligible for tenants of apartments (-0.1%). Housing represents 16% of GDP in France. Under our assumptions, GDP is affected only by the variation in the price of housing that appears in the Household Account. The effect on GDP of 1 °C warming is therefore equal to one-sixth of housing prices or rents, weighted by the proportion of the two occupier-statuses (56% for owners and 44% for tenants). By the OLS/2SLS method, GDP increases by 1.0%, and by the PSL it increases by 0.8% when temperature rises by 1 °C. This effect is substantial, contrary to the result obtained by Rehdanz and Maddison (2008), who concluded that, in Germany, the selected emissions scenario has a negligible effect because, as the authors concede, climatic variables are not measured with sufficient precision.

4.3 Who Benefits from Warming in France?

We first look at owner-occupiers of single detached housing, who are the most sensitive to climate characteristics. Table 3 takes the same variables as Table 1 and adds interaction variables with significant parameters from among those tested.

TABLE 3
Owner-Occupiers of Single-Detached Houses: Results with Interaction Variables

	owner-occupiers of single detached houses OLS	
	estimate	Pr > |t|
Mean annual temperature (°C)	0.06182	<.0001
Difference (July-mean annual temperature) (°C)	0.08312	0.0003
Difference (January-mean annual temperature) (°C)	0.03924	0.0444
July warm days (> 30° C)	-0.06131	<.0001
(July warm days)² (> 30° C)	0.00157	<.0001
July days with rainfall	0.00778	0.1432
January days with rainfall	-0.01974	<.0001
Mean annual temperature (°C) and rural space	0.02603	<.0001
Difference (July-mean annual temperature) (°C) and cities	0.02847	0.0007
January days with rainfall and poor heating	-0.01029	0.0187
July warm days (> 30° C) and garden	0.01566	<.0001
January cold days (<- 5°C) and date of construction of the structure:		
Before 1914	-0.00668	0.3676
1914-1948	0.00413	0.5602
1949-1961	-0.00181	0.8128
1962-1967	0.01734	0.0525
1968-1974	0.01522	0.0284
after 1974	0.02842	<.0001
January cold days (<- 5°C) and montain region	0.00557	0.0407

Source: Authors' results.

An extra one degree of mean annual temperature has an effect + 2.8% more than the mean effect in rural areas, or an overall effect of + 9.2% per degree Celsius. In owner-occupied detached housing in cities, an interaction variable with July temperatures has a positive parameter, showing that high July temperatures in cities are enjoyed more in detached housing than in apartments. Heatwave days have a negative mean effect, but that is reduced (by 1.6%) for houses with gardens. The effects of severe January weather are less expected than the previous ones for, while older buildings have smaller parameters, it seems that very cold January days are appreciated in recent detached housing (built after the first oil crisis in 1974). It may be that this unexpected result derives from inadequate control for the benefits procured by new or recent housing, which may be correlated with harsh winters (heat insulation is better in houses in cold regions, etc.).

Climate also has different effects depending on household heterogeneity. We do not estimate demand elasticity of climate here, as this would require data from different markets (Brown and Rosen 1982) to ensure sufficient price variability. Moreover, the second stage of Rosen's method involves serious econometric difficulties (Sheppard 1999), meaning that few workers risk using it in practice.

We analyse climate consumption for owner-occupiers of single detached houses and tenants of apartments. Climate consumption is calculated by dividing households according to quartiles of income, age of the head of the household, and number of units of consumption. We do not reproduce the results for income and household size here, as the variations are very small from one quartile to another. Table 4 shows the results for the age of the head of the household.

TABLE 4
Climate Consumption According to the Age of Household's Head

Owner-occupiers of single detached houses

quartiles of age	Q1: < 32	Q2: 32-37	Q3: 37-45	Q4: > 45
Mean annual temperature (°C)	11.34	11.46	11.63	11.83
Difference (July-mean annual temperature) (°C)	7.81	7.92	7.97	7.92
Difference (January-mean annual temperature) (°C)	-7.10	-7.22	-7.24	-7.16
July warm days (> 30° C)	5.04	5.49	5.94	6.36
July days with rainfall	7.39	7.23	7.00	6.73
January days with rainfall	11.31	10.98	10.75	10.64

Tenants of apartments

quartiles of age	Q1: < 24	Q2: 24-29	Q3: 29-37	Q4: > 37
Mean annual temperature (°C)	11.94	11.91	12.04	12.17
Difference (July-mean annual temperature) (°C)	8.04	8.08	8.17	8.16
Difference (January-mean annual temperature) (°C)	-7.37	-7.42	-7.49	-7.38
July warm days (> 30° C)	5.97	5.88	6.25	6.44
July days with rainfall	6.92	7.06	6.87	6.57
January days with rainfall	10.46	10.34	10.10	9.96

Source: Authors from INSEE housing surveys.

Consumption of mean annual temperature rises regularly with the age of the head of the household for owner occupiers of individual houses: those in the last quartile consume about 0.5 °C more than those in the first quartile (+ 4%). The variation between these two extreme groups is 1.3 for the number of very hot July days (+ 26%) and – 0.7 for the number of rainy days in January (– 6%). For apartment tenants, the variation between the two extreme groups is of the same sign but is less marked: + 2% for mean annual temperature, + 8% for very hot July days and – 5% for the number of wet winter days.

5. CONCLUSIONS

Climate is a directly-consumed, non-market good that is therefore a direct component of welfare. Analyses of the consequences of warming by cost-benefit methods do not allow for this direct effect, leading to inaccurate evaluations. In this paper, we estimate the hedonic price of climatic attributes (temperature, rainfall) from individual data on housing and wages in France. Climatic variables are obtained by local interpolation (by regression and kriging) from weather stations. Econometric estimates are obtained by two methods (OLS/2SLS and PLS) for 12,298 owner-occupied houses (9,640 single-detached houses and 2,658 apartments) and 12,062 rented dwellings (3,447 single-detached houses and 8,615 apartments) and on the wage-earners occupying the housing (19,063 people).

The results show that climate is not capitalized in wages (as in France wages are often independent of location because of national labor regulations) and that capitalization is quite high in the value of housing, especially for owner-occupiers. So, housing is worth almost 6% more when the mean annual temperature increases by 1°C. At the median point, an extra day of excessive July heat lowers housing values by 4.3% (owners) or by 1% (tenants). The effects on housing prices and rents of mean January temperatures and of the number of days of extreme cold in winter are insignificant. Rainfall affects housing prices or rents less than temperature. Moreover, consumption, production and international trade are together affected by climatic changes; macroeconomic models are required to extend this analysis in this way; this extension lies outside the scope of this paper.

References

Bastien, P., V. Esposito, and M. Tenenhaus. 2005. “PLS Generalised Linear Regression.” *Computational Statistics and Data Analysis* 48: 17–46.

Blomquist, G.C., M.C. Berger, and J.P. Hoehn. 1988. “New Estimates of Quality of Life in Urban Areas.” *American Economic Review* 78: 89–107.

Brown, J.N., and H.S. Rosen. 1982. “On the Estimation of Structural Hedonic Price Models.” *Econometrica* 50: 765–8.

Cheshire, P., and S. Magrini. 2006. “Population Growth in European Cities: Weather Matters. But only Nationally.” *Regional Studies* 40: 23–37.

Cragg, M., and M. Kahn. 1997. “New Estimates of Climate Demand: Evidence from Location Choice.” *Journal of Urban Economics* 42: 261–84.

______. 1999. “Climate Consumption and Climate Pricing from 1940 to 1990.” *Regional Science and Urban Economics* 29: 519–39.

Epple, D. 1987. “Hedonic Prices and Implicit Markets: Estimating Demand and Supply Functions for Differenciated Products.” *Journal of Political Economy* 95: 59–80.

Freeman, A.M. 1979. “Hedonic Prices, Property Values and Measuring Environmental Benefits: A Survey of the Issues.” *Scandinavian Journal of Economics:* 154–71.

Graves, P.E. 1976. “A Reexamination of Migration, Economic Opportunity, and the Quality of Life.” *Journal of Regional Science* 16: 107–12.

______. 1980. “Migration and Climate.” *Journal of Regional Science* 20: 227–37.

Graves, P.E., and P.D. Linneman. 1979. “Household Migration: Theoretical and Empirical Results.” *Journal of Urban Economics* 6: 383–404.

Gyourko, J., M. Kahn, and J. Tracy. 1999. “Quality of Life and Environmental Comparisons.” In *Handbook of Regional and Urban Economics vol. 3*, ed. Mills, E. S. and Cheshire P., *Applied Urban Economics*: 1413–54.

Henderson, J.V. 1982. “Evaluating Consumer Amenities and Interregional Welfare Differences.” *Journal of Urban Economics* 11: 32–59.

Hoch, I., and J. Drake. 1974. “Wages, Climate, and the Quality of Life.” *Journal of Environmental Economics and Management* 1: 268–95.

Hope, C. 2006. “The Marginal Impact of CO_2: An Integrated Assessment Model Incorporating the IPCC’s Five Reasons for Concern.” *Integrated Assessment* 6 (1): 19–56.

Joly D., T. Brossard, H. Cardot, J. Cavailhès, M. Hilal and P. Wavresky. 2011. “Temperature interpolation based on local information: the example of France”. *International Journal of Climatology* 31: 2141–2153.

Maddison, D. 2001. *The Amenity Value of the Global Climate.* London: Earthscan.

______. 2003. “The Amenity Value of the Climate: The Household Production Function Approach.” *Resource and Energy Economics:* 155–75.

Maddison, D., and A. Bigano. 2003. “The Amenity Value of the Italian Climate.” *Journal of Environmental Economics and Management:* 319–32.

Mendelsohn, R., W.D. Nordhaus, and D. Shaw. 1994. “The Impact of Global Warming on Agriculture: A Ricardian Analysis.” *American Economic Review* 84 (4): 753–69.

Mincer, C. 1962. “On-The-Job Training: Costs, Returns, and some Implications.” *Journal of Political Economics* 70: 850–79.

Nordhaus, W.D. 1991. “To Slow or Not to Slow: The Economics of the Greenhouse Effect.” *Economic Journal* 101 (101): 920–37.

______. 1992. "An Optimal Transition Path for Controlling Greenhouse Gases." *Science* 258 (5086): 1315–9.

Rehdanz, K., and D. Maddison. 2005. "Climate and Happiness." *Ecological Economics* 52: 111–25.

______. 2008. "The Amenity Value of Climate to Households in Germany." *Oxford Economic Papers* 61: 150–67.

Roback, J. 1982. "Wages, Rents, and the Quality of Life." *Journal of Political Economy* 90: 1257–78.

Rosen, S. 1974. "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition." *Journal of Political Economy* 82: 34–55.

______. 1979. "Wage-Based Indexes of Urban Quality of Life." In *Current Issues in Urban Economics,* ed. Mieszkowski, P. and Straszheim, M. Baltimore: Johns Hopkins University Press.

Sheppard, S. 1999. "Hedonic analysis of housing markets" In *Handbook of Regional and Urban Economics, vol. 3,* ed. Mills, E. S. and Cheshire, P. *Applied Urban Economics*: 1595–635.

Stern, N. (Dir.) 2006. *The Stern Review Report: The Economics of Climate Change*. London: HM Treasury: 603.

Stone, M., and R.J. Brooks. 1990. "Continuum Regression: Cross-Validated Sequentially Constructed Prediction Embracing Ordinary Least Squares, Partial Least Squares and Principal Components Regression." *J. R. Statist. Soc. B* 52: 237–69.

Wold, H. 1985. "Partial Least Square." In *Encyclopedia of Statistical Sciences, vol.*, ed. Kotz, S., and Johnson N.L., 581-591. New York: Wiley.

Appendix 1.
Pearson correlation coefficients between climatic variables
(Example of owner-occupier single-detached houses)

	Mean annual tempera-ture (°C)	Difference (July-mean annual temperature) (°C)	Difference (January-mean annual temperature) (°C)	July warm days (> 30° C)	Janua-ry cold days (< - 5° C)	July days with rainfall
Mean annual temperature (°C)	1.000					
Difference (July-mean annual temperature) (°C)	0.115	1.000				
Difference (January-mean annual temperature) (°C)	0.026	-0.951	1.000			
July warm days (> 30° C)	0.746	0.632	-0.470	1.000		
January cold days (< - 5° C)	-0.650	0.512	-0.606	-0.128	1.000	
July days with rainfall	-0.847	-0.242	0.030	-0.794	0.464	1.000
January days with rainfall	-0.605	-0.652	0.499	-0.802	0.064	0.735

Source: authors computations by interpolation of Météo-France climatic data.

Appendix 2: descriptive statistics
Climatic variables

	mean	std	min	max
Mean annual temperature (°C)	11.6585	1.4248	7	15.8
Difference (July-mean annual temperature) (°C)	7.9623	0.8668	5	9.8
Difference (January-mean annual temperature) (°C)	-7.2442	0.8909	-10	-4.3
July warm days (> 30° C)	5.7722	4.0067	0	23.4
January cold days (< - 5° C)	2.9790	1.9270	0	14.3
mean monthly rainfall (mm)	66.3353	15.3687	33.9917	178.025
Difference (July-mean monthly rainfall) (mm)	-12.2074	15.7812	-116.925	24.7083
Difference (January-mean monthly rainfall) (mm)	3.1912	12.0487	-38.1917	55.0833
July days with rainfall	7.0474	2.0660	1	12.1
January days with rainfall	10.7308	2.2790	4.8	17.1

Source: authors computations by interpolation of Météo-France climatic data.

Appendix 2: descriptive statistics

Wage equation

	mean	std
senior managerial	0.1357801	0.3425640
intermediate managerial	0.2136579	0.4098990
office worker	0.0538539	0.2257353
personal service providers	0.0791030	0.2699066
skilled industrial worker	0.0925265	0.2897755
skilled self-employed worker	0.0797422	0.2709009
skilled workers (other)	0.0614180	0.2401018
industrial unskilled worker	0.0820860	0.2745030
unskilled self-employed worker	0.0286582	0.1668483
farmworker	0.0143291	0.1188466
full time employment	94.4587972	15.6109294
apprentice	0.0158739	0.1249909
interim worker	0.0294572	0.1690887
limited-tenure employment	0.0798487	0.2710661
age: <19 years	0.0192297	0.1373352
age: 20–24	0.0910350	0.2876665
age: 25–29	0.1381239	0.3450392
age:30–34	0.1565546	0.3633900
age: 40–44	0.1401481	0.3471499
age: 45–49	0.1252863	0.3310521
age:50–54	0.1115432	0.3148120
age:55–81	0.0620039	0.2411691
male	0.5760933	0.4941890
4 years higher education	0.1507484	0.3578130
2 years higher education	0.1002504	0.3003415
capbepc	0.4090449	0.4916707
no educational qualification	0.1881958	0.3908789
French by naturalisation	0.0346775	0.1829664
European nationality	0.0279124	0.1647263
African nationality	0.0218399	0.1461644
other nationality	0.0044745	0.0667437
born in Europe	0.0112395	0.1054221
born in Africa	0.0132637	0.1144050
born in other region	0.9430032	0.2318426
rural commune	0.1522399	0.3592629
disadvantaged region	0.0770255	0.2666390
market size	31.3590847	54.4587101
poor commune 1000-1500K	0.0698343	0.2548744
poor commune Paris	0.0581154	0.2339677
poor commune 500-1000Kinhabitants	0.0238108	0.1524634
unemployment rate	0.1204421	0.0492953

Sources: Housing surveys (1988 to 2002) by INSEE (Institut national des statistiques et études économiques).

Appendix 2: descriptive statistics (continued)

Housing equation

	owners		renters	
	mean	std	mean	std
detached house	0.7838673	0.4116226	0.2857735	0.4518008
housing in an apartment block	0.2161327	0.4116226	0.7142265	0.4518008
1988 survey (detached house)	0.2316637	0.4219124	0.0569557	0.2317676
1992 survey (detached house)	0.1774272	0.3820454	0.0789256	0.2696337
1996 survey (detached house)	0.136445	0.3432744	0.062842	0.2426886
2002 survey (detached house)	0.2383314	0.4260802	0.0870502	0.2819204
1988 survey (housing in an apartment block)	0.060335	0.2381162	0.1217045	0.3269578
1992 survey (housing in an apartment block)	0.0500081	0.2179706	0.1967335	0.3975457
1996 survey (housing in an apartment block)	0.0410636	0.1984454	0.1886918	0.3912798
2002 survey (housing in an apartment block)	0.064726	0.2460517	0.2070967	0.4052422
living space (detached house)	112.3328838	36.2140997	90.7719756	29.9605117
living space (housing in an apartment block)	74.7599699	24.0453159	54.9673825	23.5503152
garden size (detached house)	958.4891079	1146.53	470.3263708	762.0989275
number of bathrooms (detached house)	2.5316909	0.8900301	2.2489121	0.7332841
number of bathrooms (housing in an apartment block)	2.1403311	0.5805972	1.8904817	0.4514918
poor heating	0.1026183	0.303472	0.1370419	0.3439059
room size (detached house)	23.2651831	6.1306681	22.2538758	5.7007738
size of the roons (housing in an apartment block)	22.5275005	4.8642808	23.8414523	6.3841104
garage (detached house)	0.8655602	0.341142	0.7229475	0.4476076
garage (housing in an apartment block)	0.5921746	0.4915229	0.3890888	0.4875718
cellar (detached house)	0.4221992	0.4939356	0.3785901	0.4851061
cellar (housing in an apartment block)	0.7633559	0.4251019	0.5216483	0.4995601
veranda	0.0352903	0.1845201	0.0155861	0.1238728
date of arrival in the housing	2.448203	3.8836823	1.0501575	1.0973906
before 1948 (detached house)	0.1927386	0.39447	0.4078909	0.491514
1949–1974 (detached house)	0.1207469	0.3258498	0.2164201	0.4118636
1975–1984 (detached house)	0.1060166	0.3078748	0.1430229	0.350147
after 1985 (detached house)	0.5804979	0.4935031	0.2326661	0.4225925
before 1948 (housing in an apartment block)	0.1997743	0.3999058	0.3461405	0.3461405
1949-1974 (housing in an apartment block)	0.3720843	0.4834517	0.3012188	0.3012188
1975-1984 (housing in an apartment block)	0.1617758	0.3683143	0.10296	0.10296
after 1985 (housing in an apartment block)	0.2663657	0.4421409	0.2496808	0.2496808
fireplace (detached house)	0.4068465	0.4912713	0.2251233	0.4177241
fireplace (housing in an apartment block)	0.027088	0.1623705	0.0123041	0.1102458
number of storeys of the building	1.0822085	2.8006593	2.9461118	3.3325853
ground floor	0.0307367	0.1726105	0.1316531	0.3381273
urban area, center < 30 000 inhabitants	0.0727761	0.2597791	0.0737854	0.2614322
urban area, center 30 000 – 50 000 inhabitants	0.0535859	0.2252079	0.0423645	0.2014276
urban area, center 50 000 – 100 000 inhabitants	0.0909904	0.2876072	0.0882109	0.2836131
urban area, center 100 000 – 200 000 inhabitants	0.0952187	0.2935288	0.0997347	0.2996584
urban area, center 200 000 – 500 000 inhabitants	0.126606	0.3325445	0.1713646	0.3768429
urban area, center 500 000 – 1 million inhabitants	0.0799317	0.2711985	0.1060355	0.3078958
urban area, center 1 – 3 million inhabitants	0.0822085	0.2746933	0.092522	0.2897734
urban area, center Paris	0.2027972	0.402099	0.1994694	0.3996181
rural commune	0.1386404	0.345585	0.0984911	0.2979899
peri-urban commune	0.2803708	0.4491986	0.120461	0.3255133
urban commune	0.5809888	0.4934173	0.7810479	0.4135532
population of the commune < 500 inhabitants	0.0803383	0.2718272	0.0280219	0.1650422
population of the commune 500 – 2 500 inhabitants	0.2503659	0.4332414	0.1190516	0.3238626
population of the commune 2 500 – 10 000 inhabitants	0.2454871	0.4303931	0.16581	0.3719254
population of the commune 20 000 – 50 000 inhabitants	0.1429501	0.3500362	0.1769193	0.3816162
population of the commune 50 000 – 200 000 inhabitants	0.106928	0.3090342	0.2273255	0.4191219
population of the commune 200 000 – 500 000 inhabitants	0.0387868	0.1930943	0.1169789	0.3214085
Paris	0.0202472	0.1408505	0.0669043	0.2498666
richness of the commune (log) (detached house)	3.1395885	0.2465024	3.1136964	0.2197903
block)	3.2023353	0.2443167	3.1802341	0.2627972
density	1718.28	2324.55	3058.21	2677.59
unemployment rate	0.1172443	0.0481474	0.1357735	0.0477133
evolution of the population (1990-1999)	6.0803383	10.7442968	3.8191013	8.2522482
coastal commune	0.0950561	0.2933043	0.1096833	0.3125076
commune less than 15 min from the coast	0.033664	0.1803701	0.0232963	0.1508492
harbor	0.0826964	0.2754339	0.0808324	0.2725888

Sources: Housing surveys (1988 to 2002) by INSEE (Institut national des statistiques et études économiques).

Appendix 3. Results

	owner-occupiers							
	single detached houses				apartments			
	OLS		**PLS**		**2SLS**		**PLS**	
	estimate	**Pr > |t|**	**estimate**	**p value**	**estimate**	**Pr > |t|**	**estimate**	**p value**
Intercept	9,87409	<,0001	/	/	8,892751	<,0001	/	/
1988 survey	-0,15075	<,0001	-0,04824	0,005	-0,3255	<,0001	-0,2287	<,0001
1992 survey	-0,13403	<,0001	-0,02829	0,031	-0,06711	0,0008	0,0282	0,06
1996 survey	-0,13182	<,0001	-0,02306	0,02	-0,05121	0,0156	0,04881	0,012
2002 survey	/	/	0,1059	0,001			0,09578	0,004
living space	0,00413	<,0001	0,004121	<,0001	0,007962	<,0001	0,008599	<,0001
garden size (detached house)	8,105E-05	<,0001	8,006E-05	<,0001	/	/	/	/
garden size (detached house) (square term)	-7,7E-06	<,0001	-7,58E-06	<,0001	/	/	/	/
number of bathrooms	0,08094	<,0001	0,08175	<,0001	0,085326	<,0001	0,07643	0,01
poor heating	-0,14581	<,0001	-0,1461	<,0001	-0,03264	0,2677	-0,01739	0,238
room size	-0,00339	0,1125	-0,001467	0,499	0,015499	0,0151	0,01751	0,052
(room size)²	-4,13E-05	0,2298	-7,57E-05	0,195	-0,00025	0,0242	-0,000302	0,125
garage	0,10454	<,0001	0,1072	<,0001	0,069522	0,0002	0,05512	0,006
cellar	0,06036	<,0001	0,06233	<,0001	0,073781	<,0001	0,06694	0,001
date of arrival in the housing	-0,03579	<,0001	-0,03622	<,0001	-0,02649	<,0001	-0,0269	<,0001
age of the structure	-0,00771	<,0001	-0,007371	<,0001	-0,01575	<,0001	-0,01583	<,0001
(age of the structure)²	3,896E-05	<,0001	3,626E-05	<,0001	0,00011	<,0001	0,0001106	<,0001
fireplace	0,05736	<,0001	0,05688	<,0001	0,179896	<,0001	0,1222	0,034
urban area, center < 30,000 inhabitants	-0,07608	<,0001	-0,09164	<,0001	-0,05553	0,6089	-0,02833	0,075
urban area, center 30,000 à 50,000 inhabitants	-0,05497	0,0075	-0,06209	<,0001	-0,08103	0,4575	-0,02036	0,188
urban area, center 50,000 à 100,000 inhabitants	-0,03133	0,0853	-0,04651	0,003	-0,03667	0,7292	-0,02596	0,045
urban area, center 100,000 à 200,000 inhabitants	0,02523	0,1655	0,002651	0,382	-0,06716	0,5151	-0,05251	0,01
urban area, center 200,000 à 500,000 inhabitants	0,02068	0,2464	0,006955	0,217	-0,07155	0,4852	-0,04912	0,037
urban area, center 500,000 à 1 million inhabitants	0,00512	0,8114	-0,0132	0,167	-0,04401	0,6789	-0,001648	0,465
urban area, center 1 à 3 millions inhabitants	0,0727	0,0004	0,05852	<,0001	-0,00629	0,9516	0,00802	0,382
urban area, center Paris	0,30677	<,0001	0,2921	<,0001	0,199977	0,0523	0,2212	<,0001
rural commune	-0,05166	0,0014	-0,06905	<,0001	0,007775	0,9473	-0,0147	0,295
city and suburbs commune	0,09756	<,0001	0,101	<,0001	0,113623	0,0143	0,1049	0,015
population of the commune < 500 inhabitants	-0,14947	<,0001	-0,1313	<,0001	0,144308	0,6913	/	/
population of the commune 500 à 2,500 inhabitants	-0,10587	<,0001	-0,08941	<,0001	-0,1079	0,0895	-0,04958	0,339
population of the commune 2,500 à 10,000 inhabitants	-0,04746	0,0006	-0,03367	0,065	-0,02443	0,4655	-0,01924	0,494
population of the commune 20,000 à 50,000 inhabitants	0,02858	0,0787	0,03163	0,065	0,052164	0,0401	0,03206	0,158
population of the commune 50,000 à 200,000 inhabitants	0,07578	0,0001	0,07727	0,016	0,127807	<,0001	0,104	0,026
population of the commune 200,000 à 500,000 inhabitants	0,24651	<,0001	0,2484	<,0001	0,134574	0,0005	0,09113	0,091
Paris	0,21586	0,2788	/	/	0,523102	<,0001	0,4753	<,0001
richness of the commune (log)	0,13775	<,0001	0,1513	<,0001	0,266095	<,0001	0,305	<,0001
density	1,647E-05	<,0001	0,0000175	<,0001	0,000029	<,0001	3,084E-05	<,0001
unemployment rate	-1,51771	<,0001	-1,404	<,0001	-2,47922	<,0001	-2,253	<,0001
evolution of the population (1990-1999)	0,00116	0,0012	0,001096	0,002	0,00022	0,8596	-6,47E-05	0,46
coastal commune	0,09357	<,0001	0,0897	<,0001	0,114716	0,0028	0,09776	0,031
commune less than 15 mn from the coast	0,07437	0,0002	0,0687	0,03	0,04371	0,5505	-0,009506	0,361
harbor	0,05125	0,0001	0,04428	0,001	0,057143	0,0898	0,02094	0,428
Mean annual temperature (°C)	0,0599	<,0001	0,05726	<,0001	0,057262	0,0074	0,05812	0,009
Difference (July-mean annual temperature) (°C)	0,08037	0,0004	0,06848	0,001	0,063547	0,2275	0,04482	0,135
Difference (January-mean annual temperature) (°C)	0,02591	0,1814	0,01459	0,37	0,046843	0,2858	0,01777	0,359
July warm days (> 30° C)	-0,04199	<,0001	-0,0405	<,0001	-0,01963	0,2092	-0,02498	0,109
(July warm days)² (> 30° C)	0,00149	<,0001	0,001424	<,0001	0,001413	0,0481	0,001596	0,031
January cold days (< - 5° C)	0,00669	0,4935	0,0009078	0,476	-0,01368	0,5215	-0,01974	0,229
(January cold days)² (< - 5° C)	0,0014	0,0504	0,001858	0,011	0,00268	0,1034	0,002955	0,054
July days with rainfall	0,00948	0,0723	0,007804	0,088	0,042811	0,0001	0,03886	<,0001
January days with rainfall	-0,02237	<,0001	-0,02203	<,0001	-0,01444	0,076	-0,01427	0,057

Regression results. Explained variable: log(price of the dwelling). Each line of the Table is a covariate. Method: OLS (exogenous covariates) or 2SLS (instrumental variable method when living space is endogenous) and Partial least squares (PLS). Sources: Insee Housing surveys and climatic variables interpolated from Météo-France data.

Appendix 3. Results (continued)

	Tenants							
	single detached houses				apartments			
	2SLS		PLS		2SLS		PLS	
	estimate	Pr > |t|	estimate	p value	estimate	Pr > |t|	estimate	p value
Intercept	5,366151	<,0001	/	/	5,025905	<,0001	/	/
1988 survey	-0,29258	<,0001	-0,1681	<,0001	-0,23613	<,0001	-0,1402	0,009
1992 survey	-0,16786	<,0001	-0,05179	0,001	-0,09425	<,0001	-7,4E-05	0,421
1996 survey	-0,06137	0,0001	0,06076	<,0001	-0,04786	<,0001	0,04649	0,033
2002 survey	/	/	0,1143	<,0001	/	/	0,09258	0,009
living space	0,010031	<,0001	0,009231	<,0001	0,009911	<,0001	0,009648	<,0001
garden size (detached house)	0,000028	0,1141	3,36E-05	0,026	/	/	/	/
garden size (detached house) (square term)	-5,11E-06	0,123	-6,2E-06	0,007	/	/	/	/
number of bathrooms	-0,00744	0,5762	0,008011	0,318	0,010825	0,1886	0,0174	0,267
poor heating	-0,15368	<,0001	-0,1681	<,0001	-0,04298	<,0001	-0,04495	<,0001
room size	-0,0382	<,0001	-0,03459	<,0001	-0,00207	0,141	0,000691	0,441
(room size)²	0,000397	<,0001	0,000356	<,0001	-0,00004	0,0543	-9,3E-05	0,037
garage	0,024669	0,0869	0,03182	0,019	0,018138	0,0077	0,02286	<,0001
cellar	-0,01766	0,1876	-0,0085	0,242	0,001938	0,7562	0,007144	0,303
date of arrival in the housing	-0,04987	<,0001	-0,04963	<,0001	-0,03738	<,0001	-0,03736	<,0001
age of the structure	-0,00539	<,0001	-0,00525	<,0001	-0,0057	<,0001	-0,00564	<,0001
(age of the structure)²	0,000028	<,0001	2,66E-05	<,0001	0,000038	<,0001	3,79E-05	<,0001
fireplace	0,008148	0,5774	0,01821	0,168	0,026604	0,2931	0,01049	0,082
urban area, center < 30,000 inhabitants	-0,02982	0,3325	-0,08122	0,001	-0,04999	0,0999	-0,06958	0,001
urban area, center 30,000 à 50,000 inhabitants	0,004471	0,893	-0,03718	0,155	-0,00873	0,7845	-0,01339	0,022
urban area, center 50,000 à 100,000 inhabitants	0,049531	0,0949	-0,0059	0,563	-0,01514	0,6069	-0,03375	0,012
urban area, center 100,000 à 200,000 inhabitants	0,09808	0,001	0,02375	0,003	0,024884	0,3886	0,004085	0,393
urban area, center 200,000 à 500,000 inhabitants	0,085517	0,0033	0,006764	0,198	-0,01764	0,5334	-0,02987	0,02
urban area, center 500,000 à 1 million inhabitants	0,09625	0,0048	0,008058	0,186	0,041756	0,1656	0,03093	0,014
urban area, center 1 à 3 millions inhabitants	0,111507	0,0022	0,02096	0,104	0,026326	0,3676	0,008716	0,316
urban area, center Paris	0,410022	<,0001	0,3225	<,0001	0,31061	<,0001	0,293	<,0001
rural commune	-0,01755	0,4869	-0,08567	0,001	-0,09504	0,0006	-0,1041	<,0001
city and suburbs commune	0,067806	0,0006	0,08158	<,0001	-0,00359	0,8362	0,00696	0,383
population of the commune < 500 inhabitants	-0,1121	0,0006	-0,06681	<,0001	-0,27561	<,0001	-0,2754	0,001
population of the commune 500 à 2,500 inhabitants	-0,06823	0,0091	-0,0353	0,016	-0,13712	<,0001	-0,1315	<,0001
population of the commune 2,500 à 10,000 inhabitants	-0,00071	0,9749	0,03168	0,016	-0,04449	0,0007	-0,05039	0,009
population of the commune 20,000 à 50,000 inhabitants	0,015431	0,5593	0,02043	0,041	0,027943	0,0146	0,006517	0,481
population of the commune 50,000 à 200,000 inhabitants	0,034723	0,2597	0,01205	0,03	0,04156	0,0006	0,01647	0,382
population of the commune 200,000 à 500,000 inhabitants	0,046914	0,3967	0,001433	0,184	0,037881	0,0171	0,003411	0,475
Paris	/	/	/	/	0,245218	<,0001	0,2126	<,0001
richness of the commune (log)	0,045296	0,0979	0,07457	0,015	0,143893	<,0001	0,1523	<,0001
density	0,000021	0,0003	2,74E-05	<,0001	0,000018	<,0001	1,91E-05	<,0001
unemployment rate	-0,37285	0,018	-0,1117	<,0001	-0,8475	<,0001	-0,7219	<,0001
evolution of the population (1990-1999)	0,003154	<,0001	0,003377	<,0001	0,004107	<,0001	0,004039	<,0001
coastal commune	0,074546	0,0025	0,03784	0,01	0,051313	<,0001	0,05941	<,0001
commune less than 15 mn from the coast	0,074344	0,0116	0,01804	0,412	-0,0052	0,835	-0,01389	0,044
harbor	0,056488	0,0041	0,03074	0,076	0,019369	0,0891	0,003792	0,374
Mean annual temperature (°C)	0,037957	0,0162	0,03737	0,005	0,027625	0,0005	0,02504	0,004
Difference (July-mean annual temperature) (°C)	0,062578	0,0678	0,03617	0,022	-0,00171	0,9285	-0,00223	0,453
Difference (January-mean annual temperature) (°C)	0,033658	0,2703	0,005734	0,411	-0,0109	0,5144	-0,015	0,081
July warm days (> 30° C)	-0,00714	0,4654	-0,01138	0,115	-0,02554	<,0001	-0,02361	0,001
(July warm days)² (> 30° C)	0,000237	0,4755	0,000293	0,184	0,001056	<,0001	0,000964	0,001
January cold days (< - 5° C)	-0,02078	0,1754	-0,02962	0,045	-0,00454	0,6019	-0,00886	0,218
(January cold days)² (< - 5° C)	0,003287	0,006	0,004102	0,001	0,000299	0,6781	0,000511	0,308
July days with rainfall	0,008452	0,3083	-0,0011	0,443	0,013582	0,0011	0,01394	0,002
January days with rainfall	-0,01335	0,0205	-0,01225	0,022	-0,02014	<,0001	-0,01987	<,0001

Regression results. Explained variable: log(rent of the dwelling). Each line of the Table is a covariate. Method: 2SLS (instrumental variable method because living space is endogenous) and Partial least squares (PLS). Sources: Insee Housing surveys and climatic variables interpolated from Météo-France data.

Appendix 3. Results (continued)

	wages			
	OLS		PLS	
	estimate	Pr > |t|	estimate	p value
intercept	8,48484	<,0001	/	/
senior managerial	0,56473	<,0001	0,5804	<,0001
intermediate managerial	0,17879	<,0001	0,1908	<,0001
office worker	-0,13727	<,0001	-0,1255	<,0001
personal service providers	-0,31372	<,0001	-0,3122	<,0001
skilled industrial worker	0,05538	0,0001	0,0661	<,0001
skilled self-employed worker	-0,05691	0,0002	-0,03917	0,003
skilled workers (other)	-0,01387	0,4061	0,00008014	0,421
industrial unskilled worker	-0,07718	<,0001	-0,06173	0,001
unskilled self-employed worker	-0,1582	<,0001	-0,1618	<,0001
farmworker	-0,28111	<,0001	-0,2453	<,0001
full time employment	0,01155	<,0001	0,01154	<,0001
apprentice	-0,5666	<,0001	-0,5403	<,0001
interim worker	-0,34414	<,0001	-0,3455	<,0001
limited-tenure employment	-0,34379	<,0001	-0,3403	<,0001
age: <19	-0,57992	<,0001	-0,5797	<,0001
age: 20–24	-0,34235	<,0001	-0,3255	<,0001
age: 25–29	-0,17752	<,0001	-0,1621	<,0001
age:30–34	-0,06613	<,0001	-0,05018	0,001
age: 40–44	0,03424	0,0039	0,04886	<,0001
age: 45–49	0,0494	<,0001	0,0657	<,0001
age:50–54	0,1007	<,0001	0,1204	<,0001
age:55–81	0,09387	<,0001	0,1116	<,0001
male	0,18547	<,0001	0,1774	<,0001
4 years higher education	0,09197	<,0001	0,08953	<,0001
2 years higher education	0,03469	0,0092	0,03026	0,028
capbepc	-0,05641	<,0001	-0,05637	<,0001
no educational qualification	-0,17576	<,0001	-0,1787	<,0001
French by naturalisation	-0,07915	<,0001	-0,064	0,006
European nationality	-0,039	0,2221	0,02423	0,12
African nationality	-0,09393	<,0001	-0,08251	<,0001
other nationality	-0,15937	0,001	-0,1198	0,001
born in Europe	-0,00507	0,8872	0,01504	0,019
born in Africa	-0,1259	0,0017	-0,05516	<,0001
born in other region	-0,05125	0,0765	0,003248	0,433
rural commune	-0,05078	0,0012	-0,05159	0,002
disadvantaged region	-0,02996	0,0389	-0,03389	0,021
market size	-0,03693	0,0155	-0,03331	0,026
poor commune 1000-1500K inhabitants	-0,03359	0,0096	-0,02752	0,062
poor commune Paris	0,0009621	<,0001	0,0009854	<,0001
poor commune 500-1000Kinhabitants	-0,02547	0,0574	-0,03691	0,015
unemployment rate	-0,06509	<,0001	-0,08159	<,0001
poor commune 500-1000Kinhabitants	-0,04269	0,0509	-0,03148	0,053
unemployment rate	-0,4206	<,0001	-0,3544	<,0001
Mean annual temperature (°C)	0,00245	0,7347	0,001933	0,395
Difference (July-mean annual temperature) (°C)	-0,01279	0,5443	-0,002569	0,461
Difference (January-mean annual temperature) (°C)	-0,02325	0,2086	-0,01892	0,136
July warm days (> 30° C)	-0,00185	0,4407	-0,002552	0,176
January cold days (< - 5° C)	-0,000531	0,8947	-0,00178	0,349
July days with rainfall	0,00531	0,2469	0,005169	0,127
January days with rainfall	-0,00819	0,0112	-0,007652	0,011

Regression results. Explained variable: log(wage). Each line of the Table is a covariate. Method: OLS (exogenous covariates) and Partial least squares (PLS). Sources: Insee Housing surveys and climatic variables interpolated from Météo-France data.

CHAPTER 27

Social Aspects of Climate Change in Urban Areas in Low- and Middle-Income Nations

Sheridan Bartlett, David Dodman, Jorgelina Hardoy, David Satterthwaite,* Cecilia Tacoli

1. INTRODUCTION

Hundreds of millions of urban dwellers in low- and middle-income nations are at risk from the direct and indirect impacts of climate change. As the number of people living in cities and towns has grown — more than half of the world's population now lives in urban areas — so too has the number of urban residents vulnerable to climate change.[1] The uneven distribution of vulnerability between and within urban areas and the way this is shaped by individual and household characteristics (including age, income-level, health-status, asset portfolio and gender) and by what governments do (and do not do) means that a better understanding of the social aspects of climate change in urban areas is highly relevant. Within the attempt to develop this understanding, there is a particular interest in the ways that climate change is exacerbating or will exacerbate the challenges already faced by low-income urban residents.

This paper considers the implications of climate change for social welfare and development in urban areas, with a specific focus on understanding the impacts of climate change on the most vulnerable populations. It moves beyond describing climate-related risks to assessing the more detailed implications

[1] This is not to imply that increasing urbanization necessarily brings increasing numbers of people vulnerable to climate change; it can and should bring decreasing levels of vulnerability.

*Corresponding author: david.satterthwaite@iied.org

for social relations, livelihoods and the provision of social and infrastructural services to low-income and other particularly vulnerable groups.

This paper draws on the different research projects in which its authors are engaged, including work on the vulnerability of children (Bartlett 2008a, 2008b), on the links between disasters, poverty and climate-change in urban areas in Latin America (Hardoy and Pandiella 2009), on how migration will be affected by climate change, and the role of migration in adaptation (Tacoli 2009), on community-based adaptation in the Philippines (Reyos 2009, Dodman and Mitlin 2009), on municipal government responsibilities for adaptation (Satterthwaite 2008a) and on vulnerability and risk within urban centres in the Least Developed Nations.[2] The paper also identifies existing coping strategies relying on social networks and interactions, and considers how these can be developed and strengthened into more proactive mechanisms for adaptation. Thus, there is an interest here in both the potentials and the limitations of adaptation by individuals, households and community-based organizations. Obviously, there is also a focus on the role of governments in adaptation, including the role of infrastructure and how the availability and price of land for housing influences vulnerability.

The impacts of the increased frequency and/or intensity of floods, storms and heat waves, water supply constraints and other changes that that climate change brings or is likely to bring are distributed unevenly within urban areas among different social groups. Location influences many impacts — for instance, storms, floods or heat waves usually hit particular parts of a city more severely than others. All impacts are influenced by the quality of housing and the quality and extent of provision for protective infrastructure and services. In almost all urban centres in low- and middle-income nations, there are large intra-urban differentials in the quality and extent of such provision. The unevenness in the distribution of impacts is also influenced by age and by gender, by the income levels and asset bases of individuals and households, and by their social capital. Large differentials exist within any urban population not only in the impacts but also in the potential to cope with these impacts and with recovery afterwards — and this too is influenced by age, gender and individual and household asset portfolios. Of course, it is also influenced by the speed and quality of post-disaster response from governments and international agencies. There is a particular interest here in ensuring that discussions of hazard, risk and vulnerability in relation to climate change include a consideration of the differentials among urban populations in the effectiveness of pre-disaster and post-disaster responses. Climate-change is likely to bring an ever-growing number and range of extreme-events for which complete protection is impossible (i.e. there are limits to what adaptation can protect). So adaptation is also about minimizing the impact of these events.

---

[2] This includes work on urban vulnerability and risk by the CLACC network, see www.clacc.net/

Responding to the social aspects of climate change will require commitment by a variety of urban institutions, including community-based organizations, non-government organizations, local and national governments, and international agencies. The paper identifies points of intervention, from the household to the international scale, where the activities of these actors can most effectively address the challenges of climate change and support the building of more resilient urban societies.

2. THE SOCIAL AND SPATIAL DISTRIBUTION OF VULNERABILITY AND RISK

The risks from climate change are distributed unevenly. For urban populations, this uneven distribution can be considered at different scales – for instance globally (between countries), within countries and within each urban centre. Each has relevance for understanding who is most at risk. This paper will focus primarily on the intra-urban scale, although it will also provide a brief overview of the distribution of risk in global terms. First it is important to establish just what the hazards are that contribute to these risks.

2.1 The Hazards in Urban Areas

Table 1 summarizes a variety of possible impacts from climate change on urban areas, although of course there are large differences between different urban locations in the severity of each of these hazards or resource constraints and in the mix of impacts. At least in the next few decades, the main impacts of climate-change are likely to be increased levels of risk from existing hazards.

One of the main ways that climate-change affects urban populations is through the impacts on health — mostly from physical hazards but also from extreme temperatures, increased risk of some diseases and constraints on food availability. Urban populations in places where the current burden of climate-sensitive disease is high will be disproportionately affected, primarily the urban poor in low- and middle-income countries (Kovats and Akhtar 2008). Ill-health and injury are among the most common factors in increasing poverty, both from loss of earnings and from the additional medical expenses. Table 2 summarizes the known effects of weather and climate on urban health.

TABLE 1
Climate Change Impacts on Urban Areas

Change in Climate	Possible Impact on Urban Areas
Changes in means	
Temperature	• increased energy demands for heating / cooling • worsening of air quality • high temperature impacts exaggerated by urban heat islands in cities
Precipitation	• increased risk of flooding • increased risk of landslides • distress migration from rural areas • interruption of food supply networks
Sea-level rise	• coastal flooding • reduced income from agriculture and tourism • salinization of water sources
Changes in extremes	
Extreme rainfall / Tropical cyclones	• more intense flooding • higher risk of landslides • disruption to livelihoods and city economies • damage to homes, infrastructure and businesses
Drought	• water shortages • higher food prices • disruption of hydro-electricity • distress migration from rural areas
Heat- or cold-waves	• short-term increase in energy demands for heating / cooling • health impacts for vulnerable populations
Abrupt climate change	• possible significant impacts from rapid and extreme sea-level rise • possible significant impacts from rapid and extreme temperature change
Changes in exposure	
Population movements	• movements from stressed rural habitats
Biological changes	• extended disease vector habitats

Source: Adapted from Wilbanks et al. 2007.

Climate change may affect the availability of drinking water to urban populations, particularly in urban centres lacking adequate water resource management. In most urban centres this is likely to have the greatest effect on household supplies in low-income areas, particularly informal settlements. These issues of water availability are compounded by the lack of space or storage facilities for water in low-income households. It is difficult, however, to establish the direct impact of climate change on access to clean water, as a variety of factors — social, political and environmental — determine availability.

TABLE 2
Summary of Known Effects of Weather and Climate on Urban Health

Health Outcome	Known Effects of Weather
Heat stress	• Deaths in older people and people with chronic disease increase with high and low temperatures • Heat-related illness and death due to heat waves
Air pollution-related mortality and morbidity	• Weather affects air pollutant concentrations • Weather affects distribution, seasonality and production of aeroallergens
Health impacts of weather disasters	• Floods, landslides and windstorms cause direct effects (deaths and injuries) and indirect effects (infectious disease, loss of food supplies, long-term psychological morbidity)
Mosquito-borne diseases, tick-borne diseases (e.g. malaria, dengue)	• Higher temperatures reduce the development time of pathogens in vectors and increase potential transmission to humans • Vector species require specific climatic conditions (temperature, humidity) to be sufficiently abundant to maintain transmission
Water-/ food-borne diseases	• Survival of important bacterial pathogens is related to temperature • Extreme rainfall can affect the transport of disease organisms into the water supply. Outbreaks of water-borne disease have been associated with contamination caused by heavy rainfall and flooding associated with inadequate sanitation • Increases in drought conditions may affect water availability and water quality (chemical and microbiological load) due to extreme low flows

Source: Kovats and Akhtar 2008.

The vulnerability of the urban poor to floods is evident not only in the physical impacts including injuries and deaths but also as they often experience increased rates of infectious disease (including cholera, cryptosporidiosis and typhoid fever) after flood events (Kovats and Akhtar 2008). Flood-related increases in diarrhoeal disease have been reported in India and Bangladesh; the Fourth Assessment Report of the Intergovernmental Panel on Climate Change concluded that climate change will increase the burden of diarrhoeal diseases (see Confalonieri et al. 2007). Climate change is also likely to alter the incidence and geographical range of malaria — and in many low-income and densely populated urban areas this effect is likely to be accentuated.

2.2 Inter-Urban Differentials at the Global Level

The IPCC's Fourth Assessment notes that urban centres and the infrastructure they concentrate — and the industries that are a key part of the economic base of many such centres — are often capable of considerable adaptation in order to reduce risks from the direct and indirect impacts of climate change (Wilbanks et al. 2007). All large urban centres have had to make substantial 'adaptations' to environmental conditions, site characteristics, natural resources availability and environmental hazards to be able to function — for instance, creating stable sites for buildings, putting in place the infrastructure that all cities require and ensuring provision for water and for managing wastewater and storm and surface runoff. Successful and healthy cities are proof of the adaptive capacity of their governments, citizens and enterprises. In any well-governed city, there is already a great range of measures in place to ensure that buildings and infrastructure can withstand extreme weather events and that water supply systems can cope with variations in freshwater supplies. Good environmental and public health services should also be able to cope with any increase in other likely climate change-related health risks in the next few decades — whether from heat waves, reduced freshwater availability, or greater risks from certain communicable diseases.

Thus, the climate change-related risks facing the population of any urban centre are a function not only of what climate change brings but of the quality of housing and the quality and extent of provision for infrastructure and services. Urban populations in high-income nations and a proportion of those in middle-income nations take for granted that a web of institutions, infrastructure, services and regulations protects them from extreme weather/floods, and will keep adapting to continue protecting them. Many measures to protect against extreme weather also meet everyday needs: healthcare services integrated with emergency services, and sewer and drainage systems serving daily requirements as well as coping with storms. The police, armed services, health services and fire services provide early warning, with details of what actions should be taken, and ensure rapid emergency responses. The costs are paid as service charges or through taxes and for most people represent a small proportion of their income. Consequently, extreme weather events in high-income nations rarely cause large loss of life or serious injury (Hurricane Katrina's impact was exceptional in this). Although such events occasionally cause serious property damage, the economic cost is reduced for most property owners by property and possessions insurance (Satterthwaite et al. 2007).

This adaptive capacity is also underpinned by the fact that most buildings conform to building regulations and health and safety regulations, and are served by piped water, sewers, all-weather roads, electricity and drains 24 hours a day. The institutions responsible for such services are expected to make them resilient to extreme weather. While private companies or non-profit institutions may provide some of the key services, the framework for provision and quality control is supplied by local government or local offices of provincial or national government. In addition, it is assumed that city planning and land-use regulation will be adjusted to any new or heightened risk that climate change may bring, encouraged and supported by changes in private-sector investments (over time shifting from high-risk areas) and changes in insurance premiums and coverage. At least for the next few decades, as the IPCC's Fourth Assessment stresses, this 'adaptive capacity' can deal with most likely impacts from climate change in the majority of urban centres in high-income countries (Wilbanks et al. 2007)

Thus, a consideration of risk and vulnerability for urban centres globally has to consider first which urban centres are facing or will face the largest increase in climate-change related hazards and stresses and secondly, which urban centres have the least adaptive capacity (in terms of the quality of housing, the quality and extent of provision for infrastructure and services and the quality of local government and local governance). At a global scale, the urban centres and populations facing the largest increases in climate-change related hazards are mostly in low- and middle-income nations. So too are most of the urban centres with the least adaptive capacity and the largest deficit in adaptation. It is also worth noting that most of the urban centres facing the largest increase in climate-change related hazards and with the least adaptive capacity are also urban centres with very low levels of greenhouse gas emissions per person, both historically and currently. Thus, at a global scale, climate change is bringing, and will increasingly bring, a very large transfer of risk from high-income people and nations (who are responsible for generating most greenhouse gases and who have the greatest adaptation capacity) to low-income people and nations (who have the least responsibility for generating greenhouse gas emissions, face the largest increases in hazards and have the least adaptive capacity).

At a global scale, it is possible to point to the high levels of risk and vulnerability for particular urban centres, based on case studies or on climate-change related risk maps (for instance showing which urban centres are at greatest risk from extreme-weather events or sea level rise). But there is a limited number of detailed case studies and limited capacity to predict the likely impacts of climate change for any particular locality, including how it will change over the next few decades. At a global level, according to the IPCC's Fourth Assessment Report, the vulnerabilities of industry, infrastructure, settlements and society to climate change are generally greater in certain high-risk locations. These include coastal and riverine areas, and areas whose economies are closely linked with climate sensitive resources (Wilbanks et al. 2007).

Perhaps the most relevant global trend to consider is the rapid increase in the proportion of the world's urban population and of its largest and fastest growing cities in low- and middle-income nations. Almost all the increase in the world's population over the next 20 years and beyond is likely to be in urban centres in low- and middle-income nations (UN 2008).[3] The scale of this growth is also worth highlighting; UN estimates suggest that the urban population in low- and middle-income nations has grown by more than 500 million since 2000. So available statistics — for instance on the 900 million urban dwellers living in slums and informal settlements in 2000 (UN-Habitat 2003a) or the 850 million to 1.1 billion urban dwellers lacking adequate sanitation in 2000 (UN-Habitat 2003b) — are likely to considerably understate the scale of the problem. Historically, most of the world's urban population and most of its largest cities have been in its wealthiest nations; today this is no longer so, although they are still concentrated in the largest economies (Satterthwaite 2007).

A growing proportion of both the world's total population and its urban population live in the Low Elevation Coastal Zone — and this trend is particularly evident in the Least Developed Countries (McGranahan et al 2007). (Table 3) At present, the data only allow an analysis of the rural and urban populations settled in the zone that is within 10 metres of mean sea level — so this includes more than the population at risk from likely sea level rise in the next few decades. But this still indicates the scale of the population close to the coast and in most nations the increasing proportion of the population here.

TABLE 3
Population and Land Area in the Low-Elevation Coastal Zone (LECZ) by Region, 2000

	Population and land area in LECZ				Share of population and land area in LECZ			
	Population (million)		Land ('000 km²)		Population (%)		Land (%)	
Region	Total	Urban	Total	Urban	Total	Urban	Total	Urban
Africa	56	31	191	15	7	12	1	7
Asia	466	238	881	113	13	18	3	12
Europe	50	40	490	56	7	8	2	7
Latin America	29	23	397	33	6	7	2	7
Australia and New Zealand	3	3	131	6	13	13	2	13
North America	24	21	553	52	8	8	3	6
Small Island States	6	4	58	5	13	13	16	13
World	**634**	**360**	**2,700**	**279**	**10**	**13**	**2**	**8**

Source: McGranahan et al. 2007.

[3] Although on an optimistic 'development' scenario, this may include many middle-income nations that become high-income nations. But poor economic performance may also mean a far smaller shift from rural to urban areas than anticipated in many nations (see Potts 2009).

2.3 Intra-Urban Differentials

The IPCC Fourth Assessment Report notes that "poor communities can be especially vulnerable, in particular those concentrated in relatively high-risk areas" (Wilbanks et al. 2007: 359). This is true even within high-income nations that are well served by protective infrastructure and services, which often exhibit large differentials in the risks facing their populations. For example, London is one of the world's wealthiest cities, within a high-income nation and with the resources and capacities that underpin high adaptive capacity. It is included here in part because there are so few city-based studies that have looked at differentials in vulnerability and risk within urban populations and in part because it is a reminder that there are groups that are vulnerable to climate change impacts even in wealthy cities.

Large intra-city differentials in risk are most apparent within low and middle income countries. As Revi (2008: 219) notes in regard to urban centres in India:

> "Ironically, but not surprisingly, the urban residents most vulnerable to climate change are the poor slum and squatter settlement dwellers and those who suffer from the multiple insecurities that poor governance, the lack of serious investment in the commons and a strong nexus between the political class, real estate developers and public agencies bring to cities. Through a long process of loss accumulation, they are multiply challenged by even small events that impact their livelihoods, income, property, assets and sometimes their lives. Because of systematic exclusion from the formal economy of the city — basic services and entitlements and the impossibly high entry barrier into legal land and housing markets — most poor people live in hazardous sites and are exposed to multiple environmental health risks via poor sanitation and water supply, little or no drainage and solid waste services, air and water pollution and the recurrent threat of being evicted."

For poorer groups, the main impacts of climate change in the next few decades will include a variety of impacts, both direct impacts (such as more frequent and/or more hazardous storms and floods); less direct impacts (such as reduced availability of freshwater supplies in many cities that may reduce supplies available to poorer groups); and indirect impacts (such as climate change-related weather events or changes in temperatures that reduce agricultural production and thus increase food prices or damage poorer households' asset bases) (Dodman and Satterthwaite 2008). Within any urban centre, it is common for poorer groups to be disproportionately at risk for a variety of reasons, including:

- greater exposure to hazards (e.g. through living on flood plains or unstable slopes)
- lack of risk-reducing housing and infrastructure (e.g. poor quality housing, lack of drainage systems)
- less adaptive capacity (e.g. lacking the income or assets that allow a move to better quality housing or less dangerous sites)
- less state provision for assistance in the event of a disaster (e.g. needed emergency responses and support for rebuilding or repairing homes and livelihoods; indeed, state action may increase exposure to hazards by limiting access to safe sites for housing)
- less legal and financial protection (e.g. a lack of legal tenure for housing sites, lack of insurance and disaster-proof assets).

Note here the concern for hazards and risks that occur because adaptation has been unable to prevent them. Adaptation to climate change will only be able to reduce most risks and climate-change induced costs, not prevent them. In large part, the function of adaptation is to reduce the impact of hazards because it is not possible to reduce the actual hazards (for instance, a city cannot reduce the intensity of a cyclone but can reduce its impact through better housing and infrastructure and good disaster preparedness and response). Climate change is different in this regard from many of the environmental hazards present in urban areas in low- and middle-income nations because there is no possibility of local action reducing or removing the hazard. Thus, a key part of adaptation is disaster-preparedness and disaster-response. This is an issue that is generally not well integrated into discussions of adaptation.

Much urban expansion has involved the occupation of floodplains or mountain slopes, or other zones ill-suited to settlement such as areas prone to flooding or affected by seasonal storms, sea surges or other weather-related risks (Hardoy et al. 1992, 2001). These sites are primarily occupied by low-income households, because all other 'safer' sites are beyond their means. In most cases, the poor lack formal tenure, and face not only environmental risks but also the risk of eviction. Houses are frequently built with inadequate materials, and so provide very inadequate protection against storms, fires, extreme temperatures and damp. Attention to reducing the risks faced by much of the urban population from extreme weather (unrelated to climate change) has long been lacking; this lack of attention puts many people at high risk from the likely impacts of climate change. High levels of risk are particularly evident for those who not only inhabit dangerous sites, but also those who lack the resources and options to modify conditions to lessen their vulnerability.

The growing proportion of the world's urban population living in the Low Elevation Coastal Zone was noted above; case studies of particular coastal cities show that most of those most at risk are low-income groups (see Awuor et al. 2008 for Mombasa, Revi 2008 for cities in India and Dossou and Glehouenou-Dossou 2007 for Cotonou;[4] also CLACC and IIED (2009).

In the absence of a strong information base for each locality on the impacts that climate change is likely to bring over time, the experience of groups that have been most affected by extreme weather events in the past, and more generally by climate variability, provides a basis for identifying those likely to be at risk from these in the future (see Awuor et al. 2008). However, even here available data are limited. Despite that fact that the combination of hazards and vulnerability generates environmental risks that are part of everyday life for large sections of the urban population, the number of deaths, serious injuries and loss of assets from these is not known. There are some data on the number of deaths and injuries for events registered as disasters, but this is known to be only a small proportion of all those killed or injured and/or who lost homes and assets. In part this is because the criteria for what constitutes a 'disaster' means that only large disasters are registered in official records — for instance only if at least 10 people died and/or at least 100 were reported as affected. Most of the deaths, serious injuries and loss of or damage to property caused by extreme weather globally and within most nations and cities goes unrecorded (United Nations 2009).

Even within the same geographical location, the impacts of climate change will not affect urban residents in the same way. The assessment of vulnerability — and the ways in which it is socially distributed — can perhaps best be addressed through looking at six key questions (Hardoy and Pandiella 2009):

1. Who lives or works in the locations most exposed to hazards related to the direct or indirect impacts of climate change (such as on sites at risk of flooding or landslides)?
2. Who lives or works in locations lacking the infrastructure that reduces risk (e.g. drains that reduce flood risk)?
3. Who lacks information, capacity and opportunities to take immediate short-term measures to limit impacts (e.g. to move family and assets before a disaster event)?

[4] See also Bicknell et al 2009 that brings together the city case studies published in Environment and Urbanization between 2007 and 2009

4. Whose homes and neighbourhoods face the greatest risks when impacts occur (e.g. because of poorer quality buildings that provide less protection for inhabitants and their physical assets)?
5. Who is least able to cope with the impacts (including illness, injury, loss of property, loss of income)?
6. Who is least able to avoid impacts (e.g. by building better homes, agitating for improved infrastructure, or moving to a safer place)?

The first question is on where hazards occur; the rest relate to different aspects of exposure to hazards and vulnerability to hazards. Below, each of these questions is followed by a short section considering how vulnerability is related to age, gender, household/neighbourhood assets and migration. (Age and gender are then more comprehensively considered in subsequent sections.)

2.3.1 Where Do Hazards Occur — and Who Lives or Works in the Locations Most Exposed to Hazards Related to the Direct or Indirect Impacts of Climate Change?

In urban areas, when legal land sites available for housing are scarce and/or unaffordable for low-income groups, the choices for location are limited. Individuals and households make choices that reflect their constraints, priorities and trade-offs — for instance, with regard to location/accessibility, availability, type of ownership (private or state owned), security (the likelihood of eviction), possibilities of service provision and regularization, and cost. Low-income populations often settle on land with high levels of hazard and little or no protective infrastructure, because this is the only land available to them. This is a process that has been going on for decades in most cities, so now a very considerable proportion of the population live on sites at risk from landslides, floods or extreme-winds. Box 1 gives some examples from Latin America.

The south of South America is the world's region with highest increase in annual precipitation during the 20th century (Giorgi 2003) affecting the hydrological balance in the region, especially in the Rio de la Plata basin. There is agreement amongst most scholars of the region that increased precipitation and floods, and changes in wind and precipitation patterns, are associated with climate change and will increase the risks faced by large sections of the region's population. Many urban centres here including cities such as Buenos Aires, Santa Fe and Rosario are already experiencing the effects. These cities, like so many others, were founded on the margins of major rivers on high land, but as they grew, so settlements occupied low lands and flood plains.

BOX 1

Who Lives in Hazardous Locations: Examples from Latin American Cities

Buenos Aires: The city has had a significant increase in annual rainfall over recent decades, and increasing numbers of intense rainfall events (for example, more than 100 millimetres in 24 hours) (Rebagliati 2003). Applying the DesInventar methodology that includes disasters that do not get included in official disaster records, between 1990 and 1998, 24 flood events occurred, affecting neighbourhoods of different income levels (Herzer and Clichevsky 2001). Other data indicate that between 1985 and January 2003, 35 flood events affected the metropolitan region (Rebagliati 2003). The areas most at risk are the low-lying lands of the lower basins of the rivers Reconquista and Matanza-Riachuelo and these lands have high concentrations of informal settlements (Re and Menéndez 2007). Also at risk are the city areas crossed by local streams that drain to the Rio de la Plata and these were originally settled by low-income population. Later most of these streams were channeled and covered; the area was upgraded and middle income groups moved in. However, due to a lack of completion and expansion of infrastructure works and maintenance, floods are again a recurrent problem. Not many in depth studies have looked at flood events from the perspective of those most affected (Gentile and González 2001).

Caracas: The metropolitan district of Caracas has suffered from recurrent disasters. Much of the city is built on slopes, with many gorges that lead to the main city river, the Guaire. In recent decades, the population in low-income neighbourhoods (zonas de ranchos) increased far more rapidly than the total population, resulting in far higher population densities (Cilento Sarli, 2007), As the city has expanded, land has become more impermeable, increasing water runoff. Without planning, low-income neighbourhoods have occupied unstable land and gorges and, together with their accumulated waste, they act as barriers to water runoff (Mata and Nobre 2006). In December 1999, Venezuela experienced a one in 100-year rainfall with massive landslides and floods that killed hundreds of people. The rainfall was unusual in its intensity, the time of year and in that it was not produced by either a hurricane or a tropical cyclone. The death toll among people settled on slopes and on low-lying lands was very high (ibid). The metropolitan area of Caracas occupies a valley measuring approximately 30 kilometres east to west and five kilometres north to south. Although it is a relatively small area, coordination between different administrative units (municipalities) has proved difficult. Several efforts are underway but there are difficulties in translating a theoretical model of risk management into practice (Jiménez 2006).

Viacha: Intense rains in January 2006 affected several areas in Bolivia, including the city of Viacha, where the Río Pallina overflowed — a result of heavy rains combined with the dumping of city waste into the watercourse and a lack of cleaning and maintenance. Settlements on the periphery of Viacha have expanded spontaneously and regularization and basic services come after residents have settled; most houses do not have approved plans or legal tenure. Those most affected by the rains were low-income groups, with the disaster occurring at the same time as an economic and political crisis, making it very difficult to implement the needed actions in time. Residents recall former floods in 1985 and 1995, when sewage overflowed onto the streets and damp crept into house foundations, but none were as heavy as the 2006 floods. Demands on local government have been constant.*

* "Rehabilitación urbana en Viacha, La Paz, Bolivia", accessed 4 December 2007 at http://www.hic-net.org/document.asp?PID=238.

The problem of flooding in many African cities is also worsening. In Accra, Ghana, heavy rains have been starting earlier in the year than usual, and floods frequently disrupt economic activities such as small-scale commerce, petty trading, and artisanal trades, thus affecting the ability to buy food or pay bills. In Kampala, Uganda, the construction of unregulated shelters has reduced the infiltration of rainfall and increased runoff, thereby compounding any increase in rainfall caused by climate change. Residents of low-lying coastal settlements in Lagos, Nigeria, report that flooding has become more frequent; while residents of Maputo, Mozambique also argue that flooding has become worse since 1980 (Douglas et al. 2008). In Mombasa, Kenya, it is estimated that about 17 percent of the city's land area will be submerged with a sea-level rise of only 0.3 metres, and large additional areas may be rendered uninhabitable as a result of flooding or water logging, or will become agriculturally unsuitable due to salt stress. This will particularly affect residents of peri-urban areas where agriculture is practised (Awuor et al. 2008).

2.3.2 Who Lives or Works in Locations Lacking the Infrastructure That Reduces Risk?

Two of the best documented aspects of urban development in low- and middle-income nations are first the very large deficit in provision for infrastructure and services and secondly how this deficit is concentrated in informal or illegal settlements. Thus, many of the urban neighbourhoods most at risk from extreme weather are made even more vulnerable by the lack of infrastructure and services, and often by physical changes to the site or its surrounds.

Rather than attempting to summarize the literature on this, one case will be given, to highlight impacts that arise from a combination of a lack of attention to infrastructure, increased occupation on hazardous sites and increased climate-related hazards - the case of flooding in the city of Santa Fe in Argentina. This city with around half a million inhabitants has increasingly expanded onto the Río Salado floodplain. To defend itself from floods, it had to create embankments and dykes. A flood in 2003 displaced 139,886 persons (1/3 of the city population) and 27,928 households were affected (Natenzon 2006). Official statistics indicate there were 23 deaths, although local sources suggest there were at least 100 more than this. There were also 180 cases of leptospirosis and 200 cases of hepatitis. Economic losses were estimated at approximately US$ 1 billion (CEPAL 2003) although actual losses were much larger than this but were hard to measure (for example, work and school days lost and the impossibility of carrying out informal activities to generate income). Among the factors contributing to the flood were increased and more intense rainfall and deforestation and land use changes around the city — but the flood caught the city authorities completely unprepared, even though the Instituto Nacional del Agua (INA) was monitoring water flows and had informed city and provincial government (Asociación Civil Canoa nd). More floods in 2006–2007 also caught the government unprepared: there were several deaths, tens of thousands of people had to be evacuated, highways and roads were flooded and bridges brought down. Again, one-third of the city became a shallow lake — the same part of the city that was hit by the 2003 flood. City authorities recognized that in the last 50 years there had been no official urban land policies and people had settled where and how they could, prioritizing proximity to work places or social networks. But the lack of policies is also a way of doing politics.

The devastating floods experienced by Santa Fe described above were due in part to incomplete or unmaintained infrastructure. Also, where land use has not been regulated, nobody enforced recommendations for avoiding the occupation of low-lying areas. A member of a local foundation complained that local authorities favour the settlement of at-risk areas by bringing piped water and electricity to the neighbourhoods "where they have their loyal voters" (Valente 2007). Infrastructure to defend certain city areas was meant to be in place shortly after 1998 but was never completed because of a lack of resources; and the construction of road infrastructure, such as the highway connecting the city with Rosario, created barriers to water runoff. Five years previously, studies had pointed to the need to double the size of the highway's bridges. The pumps and drainage systems installed to evacuate water in protected areas did not work because of vandalism and lack of maintenance (Natenzon 2006). Here, as in most cities, the vulnerability of large sections of the population to extreme weather is related not only to obvious economic and social factors but also to a complex mix of political factors that include a long tradition of clientelism that inhibits accountability and transparency (and excludes many groups), a lack of trust among much of the population in government institutions and civil servants and elected local politicians with a focus on the short term. "It is hard to gain votes by pointing out that a disaster did not happen" (Christoplos et al. 2001).

Besides the fact that piped water, sewers and and proper waste collection and disposal decrease health risks, when they are in place, excess water drains more easily, cesspits do not overflow and wastes do not clog drains. In Latin America, sanitation has improved; however in 2004, 125 million people (14 per cent of the urban population) still lacked a basic sanitation system (Noticias de Latinoamérica 2007) and a significantly higher proportion lacked good quality provision for sanitation and drainage (UN Habitat 2003b). The deficits in provision for water, sanitation and drainage are much larger in Africa and Asia and affect a much higher proportion of their urban populations (ibid).

2.3.3 Who Lacks Information, Capacity and Opportunity to Take Immediate Short-Term Measures to Limit Impacts?

The devastation caused in so many low-income settlements by extreme weather is not necessarily a matter of a lack of knowledge or capacities on the part of their residents, although this may be the case for some new arrivals. Residents of informal settlements are often reluctant to move away from their homes in response to an approaching storm or likelihood of a flood, even when advised to do so – for instance, for fear of losing valuables to looters, uncertainty about provisioning for their needs in the places they move to and the worry of not being allowed back if their house and settlement are damaged. There are also uncertainties about what the weather forecast actually implies for each home and household, so decisions are made in the context of stress and uncertainty.

These uncertainties are not necessarily removed by official mechanisms to inform the population on how to prepare and react in cases of disaster. In the case of the floods in Santa Fe, the accuracy of the information was in doubt. In addition, the lack of appropriate information and official evacuation mechanisms stopped many from evacuating promptly. The sense of insecurity for those living in informal settlements and the knowledge that looting usually accompanies flooding made many stay to protect their homes and assets. There is also the worry that they will not be allowed to return to their homes or settlement or that they will be relocated to other city areas far away from social and family networks, work and schools.

There are also examples of low-income populations that lack the knowledge to cope with risk. For example, in Brazil, new migrant populations from the arid northeast, with no personal experience of mudslides, arrive in Rio de Janeiro and settle on hillsides. As they clear these areas for their homes, they remove the protective vegetation cover despite government efforts to protect these areas. The lack of personal knowledge of local risk and of appropriate building techniques hinders safer practices — although many other factors also contribute, including the prevalence of crime and violence that inhibit social cohesion. Over the last 15 years, there have been large public programmes to improve conditions in the favelas, including investment in basic infrastructure, health and education for half a million poor residents (De Sherbinin et al. 2007).

2.3.4 Whose Homes and Neighbourhoods Face Greatest Risks When Impacts Occur?

Studies of disaster impacts from extreme weather in urban areas suggest that most of those who are killed or seriously injured and most of those that lose most or all their assets are from low-income groups (Satterthwaite et al. 2007, United Nations 2009). Indeed, many disasters only impact the inhabitants of particular informal settlements.

In informal settlements, houses are usually built incrementally over a number of years, with diverse materials and often without following accepted techniques for safe housing. These houses rarely comply with official safety standards and there are no controls in place. Most buildings are used intensively — with high levels of overcrowding and a mix of living and working spaces. This is often combined with a lack of maintenance and with environmental conditions (e.g. humidity from proximity to river edges and coastal areas) that cause rapid deterioration. Houses are not as solid or as insulated as they should be and are often built on inadequate foundations (many on landfill or unstable land). For instance, most informal housing begins as a single storey structure, often using many temporary materials and with little attention given to foundations; over time it is common for this to develop into more consolidated structures with more than one storey — but it is difficult to 'retrofit' the foundations and structural elements needed for safe multi-storey dwellings.

It is also difficult within informal settlements to get the needed coordination between all those living there for needed site-wide measures. In the suburbs of Buenos Aires, in low-lying lands, each resident contracts trucks to bring solid waste to their piece of land and later compact it as best they can. There is no coordination between neighbours, so plots end up on different levels; when it rains, some are flooded more than others. The natural drainage of the larger site is modified without incorporating the needed drainage infrastructure. Families often end up with water in their houses for up to a day when heavy (but not exceptional) rains occur. Houses built on stilts are rare in Buenos Aires — although there are examples, mostly in traditional low-income coastal areas. Most relatively new low-income settlements have not incorporated such measures, although building two-storey houses would allow valuable assets to be moved to the higher floor. However, this cannot always be done because of the costs and skills necessary to build two-storey houses.

Almost all low-income groups live in housing without air-conditioning or adequate insulation, and during heat waves, the very young, the elderly and people in poor health are particularly at risk (Bartlett 2008a). Here, attention is needed both to the spatial distribution of those most at risk and the spatial distribution of homes facing the highest temperatures and the least possibilities of temperature control. In most cities, a proportion of the low-income population live in tenements or cheap boarding houses in central districts with very high densities and these are often part of 'heat-islands.' Kovats and Akhrat 2008 describe how the 'urban heat island' effect is caused by day time heat being retained by the fabric of the buildings and by a reduction in cooling vegetation. This has the effect of raising night time temperatures by 1-5 degrees in temperate latitudes and up to 10 degrees C in tropical cities, especially during the dry season (ibid).

In northern Mexico, heat waves have been correlated with increases in mortality rates; in Buenos Aires, 10 per cent of summer deaths are associated with heat stress; and records show increases in the incidence of diarrhoea in Peru (Mata and Nobre 2006). Cold spells are also becoming more frequent in some locations, and without proper heating and housing insulation they are also difficult to cope with. In July 2007, it snowed in Buenos Aires for the first time in almost 100 years. There are no available data, however, on death tolls and health impacts related to unusual and extreme temperatures.

The expansion of the range of dengue, malaria and other communicable diseases is related to changes in temperature and precipitation. No studies that we know of specifically associate disease risks and vulnerability to climate change. However, we can assume that low-income groups will be most at risk as they live and work in homes and neighbourhoods where public health measures to eliminate disease vectors are absent or ineffective.

2.3.5 Who is Least Able to Cope with Impacts?

The increased health risks noted above become all the more serious if those who get sick (or injured by extreme events) have to rely on overtaxed and often ineffective health care systems, and lose school and work days to health problems that should have been prevented. Here the speed and effectiveness of post-disaster response has such relevance for helping the groups affected to cope with the impacts — for instance in making immediate provision for safe locations for those who have been displaced, in rapid and effective treatment for those who are injured and in supporting those who have been displaced to plan and implement their own individual, household and community recovery (Reyos 2009). For most disasters, all the above depends on local capacities because they do not attract the attention of international agencies (United Nations 2009).

Obviously, those with the lowest paying jobs in the informal economy face particular difficulties in coping. Most of those who work in the informal economy lack health insurance to cover income lost to illness, injury or death. Income lost to illness or injury or the accidental death of an income-earner remains one of the most common causes of impoverishment; so too are the additional costs imposed on households with sick or injured members from health care and medicines (see for instance Pryer 1993, 2003).

The vulnerability of low-income individuals or households to virtually all stresses and shocks, including those that are climate-related, is influenced not only by income-levels but also by the scale and nature of the assets they possess or can draw on. The asset-portfolios of individuals, households and communities are a key determinant of their adaptive capacity both to reduce risk and to cope with and adapt to increased risk levels (Moser and Satterthwaite 2008). Here, assets "are not simply resources that people use to build livelihoods: they give them the capability to be and act" (Bebbington 1999, page 2029). This is a point to which this paper returns in the final sections.

The factors influencing who is least able to cope with climate-change related impacts can be divided into personal or situational. Personal factors are related to the characteristics of the individual who may be affected. Age is perhaps the most important of these — and will be discussed in detail below. Existing health problems and disabilities, including mental difficulties resulting in impaired cognition, can also reduce the capacity of people to respond in emergencies. Situational factors may include housing (the type of building and its condition) and the work environment. People in certain occupations are particularly vulnerable to heat stress, including those involved in heavy manual labour such as rickshaw-pullers (Begum and Sen 2005). However, a broad range of social factors also affect vulnerability, with people living alone or with limited family or social networks facing more difficulties in coping with shocks and stresses, including those related to climate change. Among the groups that have particularly high levels of vulnerability to some or most aspects of climate change are children, women and migrants; separate sections later in this paper consider why this is so. Low-income groups in general, women, children and the elderly seldom have much influence in regard to what is done for disaster preparedness or responses.

2.3.6 Who is Least Able to Adapt to Avoid Impacts?

The large differentials between locations within and around most cities in the scale and nature of climate-related hazards and in the quality of housing, infrastructure and services means that where you live and work influences your level of risk. Households and enterprises can 'buy' their way out of risk by choosing safer sites and sites with good quality buildings and infrastructure. 'Good governance' should be able to greatly diminish these spatial differences in risk, for instance by ensuring that low-income groups can find accommodation in safe sites with good infrastructure.

So in large part, adaptation capacity relates to being in or moving to low-risk locations. Most larger companies and corporations can move from a city-site or city if climate-change risks increase. It is possible to envisage a trend in new investments by larger companies and corporations away from cities and city-sites most at risk from floods, storms and sea-level rise that will hardly affect their operations. They have long been adept at shifting production to locations where profits are maximized and it is easy for them to factor in risks from climate change. But it is difficult to conceive of how many of the largest successful coastal cities most at risk from storms and sea level rise will manage. Cities such as Mumbai, Shanghai and Dhaka are very vulnerable to sea-level rise. All are very large (each has well over 10 million inhabitants), all have had considerable economic success in the last few decades, all have great importance to their nations' economies and cultures, all concentrate very large investments and economic interests. Many other cities that have great economic importance for their nation face similar problems — for instance Alexandria, Dar es Salaam and many cities on the coast of West Africa. Most residents and smaller businesses have far less possibilities of moving — and face far more serious losses if the value of their properties decline. Many low-income households have their livelihoods and assets tied to particular cities or city sites. Meanwhile, the movement out of larger companies and corporations also threatens the city's economic base and the livelihoods of those who worked for these companies or provided goods and services to them or their workforces.

In many cities, middle- and high-income groups also settle in some neighbourhoods in risk areas near rivers or coastal areas or on slopes, but they have a choice and the assets (capital, contacts, political influence etc.) to reinforce their house structures, get protective infrastructure, and lobby for policies and actions that protect their homes and neighbourhoods; their homes and possessions are also often protected by insurance (although if hazard-levels increase, insurance premiums will go up or may not be available).

2.4 Age and Vulnerability[5]

Children, especially young children, are in a stage of rapid development and are less well equipped on many fronts to deal with deprivation and stress. Their more rapid metabolisms, immature organs and nervous systems, developing cognition, limited experience and behavioural characteristics are all at issue here. Their exposure to various risks is also more likely than with adults to have long-term repercussions. Almost all the disproportionate implications for children are intensified by poverty and the difficult choices low-income households make as they adapt to more challenging conditions. Events that might have little or no effect on children in high-income countries and communities can have critical implications for children in poverty.

Urban children are generally better off than their rural counterparts, but this is not true for the hundreds of millions living in urban poverty. Without adequate planning and good governance, poor urban areas can be among the world's most life-threatening environments (Hardoy et al. 1990; Van den Poel et al. 2007). In some informal settlements, a quarter of all children still die before the age of five. Nor does the "urban advantage" come into play in terms of education and life opportunities for most of those in poverty. In many urban areas, the risks children face are likely to be intensified by climate change.

Although children are disproportionately at risk on many fronts, it is a mistake to think of them only as victims in the face of climate change. With adequate support and protection, children can also be extraordinarily resilient in the face of stresses and shocks. Moreover, there is ample documentation on the benefits of having children

[5]This draws directly from Bartlett 2008b

and young people active, informed and involved in responding to the challenges in their lives, not only for their own learning and development but also for the energy, resourcefulness and knowledge that they can bring to local issues.

There is not enough hard knowledge about the implications of climate change for children to present a comprehensive picture. Even where more general impacts are projected, figures are seldom disaggregated by age. But it is possible to extrapolate from existing knowledge in related areas: work on environmental health in urban areas, disaster responses, household coping strategies, the effects on children of urban poverty, children's resilience, and the beneficial effects of their participation in various efforts all contribute to a picture of the implications of disasters as well as more gradual changes, and the adaptations likely to be made.

However, various events associated with climate change have clear impacts on child health and survival:

- Mortality in extreme events: In low-income and many middle-income countries, the loss of life is shown repeatedly to be disproportionately high among children, women and the elderly, especially among the poor during such extreme events as flooding, high winds and landslides. A study of flood-related mortalities in Nepal, for instance, found that the death rate for children aged two to nine was more than double that of adults; and pre-school girls were five times more likely to die than adult men. The risk for poor households was six times that of higher-income households (Pradhan et al 2007).

- Water and sanitation-related illnesses: Children under five are the main victims (80 per cent globally) of sanitation-related illnesses (diarrhoeal disease primarily) (Murray and Lopez 1996) because of their less developed immunity and because their play behaviour can bring them into contact with pathogens. This also results in higher levels of malnutrition and increased vulnerability to other illnesses, with effects on overall development. Droughts, heavy or prolonged rains, flooding and conditions after disasters all intensify the risks, which are already very high in poor urban areas; so too may climate-change related constraints on fresh water supplies in many urban centres.

- Malaria and other tropical diseases: Warmer average temperatures are expanding the areas where many tropical diseases can occur, with children most often the victims. In many locations, the most serious threat is malaria. Up to 50 per cent of the world's population is now considered to be at risk. In Africa, 65 per cent of mortality is among children under five (Breman et al. 2004). Malaria also increases the severity of other diseases, more than doubling overall mortality for young children.

- Heat stress: Young children, along with the elderly, are at highest risk from heat stress. Research in São Paulo found that for every degree increase above

20°C, there was a 2.6 per cent increase in overall mortality in children under 15 (same as for those over 65.) (Gouveia et al. 2003). Risks for younger children are higher. Those in poor urban areas may be at highest risk because of the "urban heat-island" effect, high levels of congestion and little open space and vegetation (Kovats and Akhtar 2008)

- Malnutrition: Malnutrition results from food shortages (for instance as a result of reduced rainfall, other changes affecting agriculture, interruptions in supplies during sudden acute events) and is also closely tied to unsanitary conditions and to children's general state of health. If children are already undernourished, they are less likely to withstand the stress of an extreme event. Malnutrition increases vulnerability on every front and can result in long-term physical and mental stunting.
- Injury: After extreme events, injury rates go up. Children, because of their size and developmental immaturity, are particularly susceptible and are more likely to experience serious and long-term effects (from burns, broken bones, head injuries, for example) because of their size and physiological immaturity (Berger and Mohan 1996).
- Quality of care: As conditions become more challenging to health, so do the burdens faced by caregivers. These problems are seldom faced one at a time – risk factors generally exist in clusters. Overstretched and exhausted caregivers are more likely to leave children unsupervised and to cut corners in all the chores that are necessary for healthy living.

For some children in some places, the added challenges brought by climate change could contribute to an erosion of both their mental capacity and their opportunities for learning and growth. Abundant research relates lower cognitive capacity and performance to under nutrition, intestinal parasites, diarrhoeal diseases, malaria, maternal health and nutrition during pregnancy, as well as maternal stress during and after pregnancy. Learning is also dependent on supportive social and physical environments and the opportunities to master new skills. When supportive environments break down, so do opportunities for engagement in purposeful goal-directed activities. Disaster can also result in the interruption of formal schooling for months at a time, and children are more likely to be withdrawn from school when households face shocks.

Levels of psychological vulnerability and resilience depend on children's health and internal strengths as well as household dynamics and levels of social support. Children who have experienced success and approval in their lives are more likely to adapt well than those who have suffered rejection and failure. Poverty and social status can play an important role in this regard. But without question, the losses, hardships and uncertainties surrounding stressful events can have high costs for children. Increased levels of irritability, withdrawal and family conflict are not unusual after disasters. Even gradually worsening conditions can contribute to mental health problems, which are closely tied to unpredictability, uncertainty and general insecurity. High stress for adults can have serious implications for children, contributing to higher levels of neglect. Increased rates of child abuse have long been associated with such factors as parental depression, increased poverty, loss of property or a breakdown in social support.

Displacement and life in emergency or transitional housing have been noted in many contexts to lead to an erosion of the social controls that normally regulate behaviour within households and communities. Overcrowding, chaotic conditions, lack of privacy and the collapse of regular routines can contribute to anger, frustration and violence. Adolescent girls especially report sexual harassment and abuse. The synergistic and cumulative effects of such physical and social stressors can affect children's development on all fronts. As the numbers of displaced people grow, these dysfunctional environments are likely to become the setting within which more and more children spend their early years. Children's capacity to cope well in these difficult situations has been related to their own active engagement, opportunities for problem solving and for interaction with peers, and the presence of at least one consistently supportive adult in their lives.

Even less extreme events can create havoc in families' lives, deepening the level of poverty. When times are hard, children can become an asset that is drawn on to maintain the stability of the household. Children may be pulled from school to work or take care of siblings. Some children may be considered more "expendable" than others. Many of Bombay's young prostitutes are from poor rural villages in Nepal, where inadequate crop yields lead families to sacrifice one child so others may survive.

2.5 Gender and Vulnerability

In most urban centres, there are large differences between women and men in regard to their exposure to climate-related hazards, and their capacity to avoid, cope with or adapt to them. It usually falls to women and often to older girls to cope with all the increased risks and vulnerabilities facing children. Within low-income populations, women often have particular risks and vulnerabilities related to gender relations — because of the tasks they undertake and the responsibilities they bear, the discrimination they face in accessing jobs (which also means lower incomes), resources (for instance property titles or control of income or expenditure within households) and services, and their generally lower status within many households and communities.

One indicator pointing to the higher burdens and stresses faced by women is the evidence globally of the higher incidence of mental health problems among women, especially poor women in low income countries (WHO 2001). This evidence is not specifically related to climate change, but many of the risk factors for such common mental problems as anxiety, depression, insomnia and irritability are likely to be exacerbated by some of the effects of climate change. There is growing evidence, for instance, both from high- and low-income countries, of significant associations for women between food insecurity and anxiety and depression (Heflin et al. 2005; Hadley and Patil 2007). More generally, these common mental health problems are considered to be related to unpredictability, uncertainty and general insecurity (Patel et al. 1999, WHO 2001), These factors are undoubtedly intensified by many of the effects of climate change. Women also speak of the punishing workloads they face in the context of poverty and adversity, and the resulting fatigue, anxiety and "problems of the mind" that characterize their days. They describe headaches, unhappiness, disturbed sleep patterns and just "thinking too much" as undermining their capacity to cope adequately with their lives and their children (Aidoo and Harpham 2001; Avotri and Waters 1999). Mental health problems obviously also affect men; yet the particular gender-related burdens faced by women may increase their vulnerability to climate-related shocks and stresses.

These stresses and vulnerabilities often become most evident after events that destroy or damage homes and neighbourhoods. When homes are destroyed or damaged, this often affects women's incomes more than men's as they undertake income-earning activities from home and so lose the income when the house or the equipment they used is lost. As noted above, where women take most responsibility for children, they are more constrained in their capacity to move rapidly — for instance to avoid flood waters. Women generally spend more time in and around the home because they have most of the child rearing and house management tasks and/or work from home; in some societies, women are constrained by social norms from being able to leave the home. Where homes and settlements are at particular risk from climate shocks, these factors all act to increase the level of risk faced by women. This helps to explain why many climate-disasters have mortality rates among women significantly higher than for men. Although the Indian Ocean Tsunami was not related to climate change, its impacts illustrate differentials in vulnerability; in India, Indonesia and Sri Lanka, Oxfam America found mortality in women was between three and four times that of men (Renton and Palmer 2005).

For populations that have to move — either temporarily or permanently — it is rare for women's needs and priorities to be addressed or even considered in the temporary or resettlement accommodation. There are also case studies showing the particular disadvantages and risks that women face after disasters — and, within this, instances of the particular problems faced by women-headed households and widows (Enarson, 2004). Within the chaos of temporary camps and even of more permanent resettlement, little attention is paid to housing, settlement forms and services that address the personal safety of girls and women, with higher risk of gender-based violence, abuse and maltreatment associated with household stress and/or displacement (Bartlett 2008a, 2008b). Child-rearing and domestic responsibilities can become even more onerous and time consuming in this context, with greater difficulties, for instance, in getting food, fuel and water,.. At the same time women "struggle in the fast-closing post-disaster 'window of opportunity' for personal security, land rights, secure housing, employment, job training, decision-making power, mobility, autonomy, and a voice in the reconstruction process" (Enarson and Meyreles 2004: 69).

Equally problematic is the failure to recognize women's individual and collective capacities for recovery and reconstruction as community leaders, neighbourhood networkers, producers, gardeners, rainwater harvesters, and monitors of flood prone rivers. This means that their resources, capacities, assets and hard-won knowledge about how to make life safer and live with risk are all ignored. Examples show that supporting women's involvement in reconstruction and in rebuilding their livelihoods not only benefits women but also their communities (Enarson 2004).

3. The Social Implications of Responses to Climate Change

Climate change has differential impacts within society. The following sections examine the social and political implications of mitigation and the potential social consequences of adaptation, both formal and informal. Mitigation and adaptation both incur costs — but both also have the potential to provide a broader suite of benefits in both the short- and the long-term. Mitigation is about reducing the hazards while adaptation is reducing vulnerability to the hazards. Yet mitigation and adaptation projects also need to be assessed critically to examine the consequences that these may have for different social groups. There are few specific examples of these assessments — largely because there have been only a limited number of projects of this type in cities in low- and middle-income countries. But investments in flood protection often serve only a portion of the city's population and businesses — as is the case in such investments to date in Dhaka (Alam and Rabbani 2007). There are many examples of 'environmental' projects in cities that have served only the narrow interests of wealthier groups, or that have included an active anti-poor political agenda. Indeed, while many traditional approaches to improve urban environmental health (e.g. subsidising public water, sewers and conventional solid waste collection) can undermine sustainability, some of the new approaches promoted by those concerned primarily with ecological sustainability (e.g.

demand management applied to water when much of the population lack piped supplies) can undermine the health of the urban poor (McGranahan and Satterthwaite 2000). David Harvey (1996: 182) states the case somewhat bluntly: "A cynical observer might be tempted to conclude that discussion of the environmental issue is nothing more than a covert way of introducing particular social and political projects by raising the specter of an ecological crisis or of legitimizing solutions by appeal to the authority of nature-imposed necessity". An extreme example of this is Operation Murambatsvina in Zimbabwe, characterized by government officials as a 'clean up' to reduce the spread of infectious diseases; yet this was actually one of the largest and most violent examples of forcible slum clearance driven by political motives (Tibaijuka 2005). Large-scale evictions in Delhi in recent years have in part been justified on environmental grounds, as low-income groups and their informal settlements are accused of pollution they did not create, but these primarily serve middle-class interests and increase poverty (Bhan 2009). In Surabaya, the city government has been seeking to clear long-established low-income settlements along the riverside by claiming that they are responsible for polluting the river and filling it with waste (which in turn increases flooding) even though the inhabitants of these settlements make little contribution to these problems (Some, Hafidz and Sauter 2009).

Urban policies have a key role in both adaptation and mitigation, particularly as urban areas concentrate more than half the world's population and more than 90 percent of the value of economic activities.[6] Although many estimates of the contribution of cities to global anthropogenic greenhouse gas emissions overstate their contribution and under-state the contribution of smaller urban centres and rural areas (Satterthwaite 2008b, Dodman 2009), the extent of the population living in cities and the concentration of production and of populations with high-consumption lifestyles in cities means that they have a key role to play in the reduction of greenhouse gas emissions. (Although so too do urban centres too small to be cities and rural areas, especially those that concentrate high-income groups). Good land-use and transportation planning can contribute to reducing urban carbon footprints, and can de-link economic success from high greenhouse gas emissions. Urban authorities also have a key role in developing appropriate building standards and regulations that can encourage energy efficient buildings and reduce emissions from industry, commerce, and services.

[6]Industry and services account for 97 percent of industry and services (Satterthwaite 2007) and most industries and service enterprises are in urban areas.

3.1 The Social and Political Implications of Mitigation

As part of a broader, long-term policy of responding to climate change, there is obviously a role for mitigation in all city development strategies. But for most urban centres in low- and middle-income nations, a focus on building the capacity of individuals, households, community organizations and local governments to respond to climate change through adaptation is a much higher priority. For most urban centres in low- and middle-income nations, an emphasis on mitigation is not only unfair — given that these urban centres and their residents have made minimal contributions to greenhouse gas emissions — but also ineffective (because there is not much to mitigate).

Effective responses to climate change require both adaptation and mitigation. Mitigation can be considered the most important contribution to adaptation, because if it is successful on a global scale, it can greatly reduce the need for adaptation in almost all localities. This would be particularly valuable to the many cities, smaller urban centres and rural areas in low-income nations that have so little adaptation capacity, however much funding the international system might make available to them. The difficulties in building adaptive capacity in many of the urban centres most at risk from climate change (especially for low-income groups) adds greatly to the urgency of achieving global agreements that rapidly reduce total greenhouse gas emissions and avoid 'dangerous' climate change. But greenhouse gas emission reduction of the scale and speed needed to avoid this is very unlikely, in large part because this necessitates substantial constraints on high-consumption lifestyles in high-income nations and with the main benefits being less increase in risk levels for low-income groups in low- and middle-income nations.

The anticipated increase in the urban population in low- and middle-income nations over the coming decades (which will accommodate most of the global growth in population) means that greenhouse gas reduction measures will need to be adopted here too, if dangerous levels of climate change are to be avoided. Successful mitigation globally depends on ensuring that the development of urban centres in low- and middle-income nations do not mirror the resource-hungry and carbon-intensive development pathways of urban centres elsewhere.

However, there are two areas in which mitigation might have serious social consequences for urban populations in low- and middle-income nations: first, if mitigation detracts attention from adaptation; and secondly, if mitigation measures have damaging impacts on sections of the urban population (for instance through the eviction of urban poor groups from 'unsafe' sites). Authorities in some of the larger cities in middle-income cities appear to place a particularly high priority on mitigation as their response to climate change – at least partially in response to highly publicised global initiatives that appear to generate positive publicity and provide an entry point into an elite group of cities.

There is some recognition that climate change mitigation efforts may have disproportionately negative impacts on some of the groups that are most vulnerable to climate change impacts; "for the world's poor, policies to mitigate climate change may, in the short term, have as much impact as climate change itself" — particularly in the areas of green growth strategies, environmental labelling policies, biofuel production policies and forest carbon policies (Prowse and Peskett 2008: 1). An increasing emphasis in high-income nations on imported goods meeting externally-audited environmental standards may hugely disadvantage many small producers from low-income nations.

Mayors and city officials around the world dream of transforming 'their city' into a 'world class city'. In this, they are often much influenced by 'successful' cities that they have visited or read about, such as Dubai, Singapore or Shanghai. This often leads to city government support for projects, programmes, and partnerships with powerful private-sector interests that have very large carbon footprints (in their construction and functioning) and also do little or nothing to address the key needs of low-income urban residents (including addressing the infrastructure deficit). In many cases, city governments view the poor, their settlements, and their income-generating activities as 'the problem' (even as these same people are central to the city's economy and their settlements and livelihoods have very small carbon footprints). This situation is often exacerbated by strong middle class interests that push city and municipal governments towards positions that are anti-poor, anti-vendors, anti-street, anti-pedestrian, and anti-mixed use (Hasan 2005).

Singapore has long served as an example that captures the imagination of politicians and developers. But this is without any recognition of what has actually underpinned Singapore's development - one of the fastest growing economies in the world over a long period, a very small population, almost entirely urban, and so no rapid rural-urban migration boosting the city's population growth, and much of the land in public ownership. More recently, Shanghai and Dubai have increasingly been used as examples to which cities should aspire, but these are hardly models of participatory democracy and again, these are within nations that have enjoyed very rapid growth over decades. If 'city development' so often involves massive evictions of low-income groups (see Hasan 2005, du Plessis 2005, Bhan 2009), it is likely that official responses to mitigation (and adaptation) may also be similarly anti-poor.

Many urban authorities in high-income nations have, quite rightly, made significant statements and efforts in relation to the reduction of greenhouse gas emissions. Although international relations approaches to addressing climate change, such as those overseen by the United Nations Framework Convention on Climate Change (UNFCCC), have tended to treat the nation state as a single unit, many cities have been successful at pursuing mitigation goals separate and apart from those committed to at a national scale (Bulkeley and Betsill 2004). In New York City, Mayor Michael Bloomberg has made a commitment to reduce the city's emissions by 30 percent below 2005 levels by 2030 (PlaNYC 2007), despite the expected increase in population of almost a million people in the same period. London has set a target of achieving a 60 percent reduction from 2000 levels by 2050 (Mayor of London 2007). Some similar efforts can also be seen in low- and middle-income nations: for example, the Mayor of Makati City (in Metro-Manila, Philippines), Jejomar Binay, announced the intention of his city to reduce its greenhouse gas emissions by 20 percent by 2010.[7]

However, for most low-income nations, greenhouse gas emissions are so low that there is not much to mitigate. Many low-income nations have emissions per capita that are less than 1/200th that of the United States and Canada.[8] In 2005, greenhouse gas emissions per person were around 23 tonnes of carbon dioxide equivalent in the United States and Canada, between 6 and 12 tonnes in most European nations — and less than 0.25 tonnes for many nations in sub-Saharan Africa. Several sub-Saharan African nations have per capita emissions of less than 0.1 tonnes. These nations' per capita figures are also far below the targets for the world average sought for 2030 or 2050 to slow and then stop climate change. The 100 'Most Vulnerable Countries' (composed of the Least Developed Countries, Small Island Developing States, and Africa) that are home to well over one billion people account for less than five percent of total global emissions (Huq and Ayers 2007).

There is much less data available on GHG emissions per person for cities. The limited data available show that cities tend to have per capita emissions well below their national averages although there is little data on cities in low- and middle-income nations (Dodman 2009). But for cities in high-income nations, this is in part because the greenhouse gases that go into the making and distribution of goods purchased and used by their population are assigned to the city (or nation) where they are produced, not to the person that buys, uses and disposes of the goods (or their city or nation). If greenhouse gas emission inventories were able to assigned emissions to those whose consumption caused the emissions, this would show a larger contribution from cities (small towns and rural areas) with high concentrations of middle and upper income groups with high-consumption lifestyles (Satterthwaite 2009).

In many urban centres and countries, a focus on mitigation so often promoted by northern-based initiatives may serve to divert attention from the more immediate issues of adaptation, and particularly how climate change is likely to affect the urban and rural poor. It is also easier for international agencies

---

[7] *Manila Bulletin* 8/10/08

[8] The figures on per capita carbon dioxide emissions are drawn from World Development Indicators On-line; https://publications.worldbank.org/ecommerce/

to promote mitigation than to promote the much needed but messy, complex process of pro-poor adaptation.

The enthusiasm for promoting mitigation in cities in low- and middle-income nations suggests a need to develop GHG emission inventories for cities. But there are social implications to consider as cities become classified and ranked by their GHG emissions and per capita emissions. Allocating to cities the GHG emissions arising from production within their borders puts cities producing energy intensive goods at a disadvantage. So a city that was a centre for the production of (say) windmills, photovoltaic panels and hydrogen-powered buses would have the greenhouse gas emissions that go into their fabrication counted as the responsibility of that city but the city would not get credited with the GHG emissions reduced by the use of its products in other locations. Meanwhile, a city with a high concentration of people with high-consumption lifestyles would have its GHG emissions kept down if most of the goods used in the city that have large carbon footprints are imported. In addition, if a city's performance in GHG emissions or in emissions reduction becomes important in, for instance, attracting investment or obtaining concessional finance, there are so many ways in which figures can be tweaked — for instance by the choice of city boundaries (e.g. excluding wealthy low-density suburbs with very high private automobile ownership and use) or by how particular emissions sources are treated (do cities get allocated the emissions generated by the transport used by commuters who live outside the city or the emissions from airplanes that refuel in that city's airport or the emissions from distant power stations when much of the electricity they generate is used within the city?) More generally, a focus in city-based GHG emissions may encourage a focus on mitigation when for most urban centres in low- and middle-income nations, a much higher priority should be given to adaptation.

Some mitigation may be made to work in favour of the urban poor or to include benefits for them. Shifts in power generation to reduce carbon emissions may also reduce air pollution — especially if these involve a shift from coal and oil-fired power stations with little or no pollution control. Improving and extending public transport and measures to encourage walking and bicycling may also contribute to better air quality and also better meet the mobility needs of low-income urban residents. The TransMilenio public transport system in Bogotá, Colombia has been successful at meeting the needs of the 80 percent of the city's population that is dependent on public transportation, including the 53 percent who are defined as living in poverty (Héron 2006). But obviously, all improvements in public transport serve particular groups and locations better than others and often many of the urban poor get little or no benefit because their neighbourhoods are not served or the fares are too high. A low-income neighbourhood in Montevideo even got named 'barrio nicol' because it had no bus service ('ni colectivo).

It may be that 'slum' and squatter upgrading or new house initiatives that serve low-income groups can also incorporate equipment and design features that limit carbon emissions — as in a housing project in Kuvasa, South Africa where low-cost housing was provided with energy efficient lighting, solar water heaters, and ceiling insulation — while being funded through carbon financing.[9] But care is needed to make sure that what is provided actually meets inhabitants' needs. The past record on this is not so good — for instance the enthusiasm for pushing 'energy efficient stoves' onto low-income households 'to reduce deforestation' that did not work or that failed to meet their needs (see Sarin 1991 for example). And in terms of mitigation effectiveness, it is the middle and upper-income groups that need to use energy efficient lighting, solar water heaters and house designs that minimize the need for heating and cooling, more than the low-income groups, since they are greater energy consumers.

3.2 Adaptation: Responses and Social Implications

Initiatives to adapt to environmental change (including those to which climate change contributes) are undertaken by many actors and at many levels – from large formal government and international agency funded efforts to the small risk management decisions made at the household level. These measures affect not only environmental and economic realities; they also have social consequences, and sometimes these may be unexpected or unintended. When the social aspects are taken into consideration, it can provide a different perspective on their practicality or success. For instance, many climate change adaptation strategies advocated by government or donors may actually have unintended negative consequences for the poor. Conversely, a strategy that is most often frowned on by policy makers, i.e. migration, can actually be a constructive way for households to adapt to changing realities

3.2.1 Formal Responses; the Unintended Consequences

To date, considerations for adaptation have been driven by a discourse of urgency — because of the scale of the potential challenges, and the rapidity with which change may take place. However, a failure to fully consider the impacts of some of the actions that are being taken or considered to promote adaptation can end up penalizing those who will be (or are already) hardest hit by climate change.

One example of this is the consequences of developing and enforcing more rigorous building and infrastructure standards. Such standards serve an important purpose in ensuring that houses, commercial buildings and infra-

---

[9] see www.ssnafrica.org

structure are safe and provide an adequate standard of protection from weather and other factors. However, a large proportion of the houses in urban areas in low and middle-income countries and most new housing that is constructed do not meet existing standards – and in many cases the problem is less with the houses themselves but more with the regulations that fail to reflect what is possible locally. One aspect of this is the absence of appropriate regulations for the process of incremental construction that is at the core of the strategies adopted by a high proportion of low-income urban residents to obtain housing. There are examples of building-standard changes that have been made in response to dialogues between city authorities and representative organizations of the urban poor (Muller and Mitlin 2007, Manda 2007) but these are exceptions (and were not done in response to climate change but in order to lower prices).

It is very easy to recommend more rigorous building standards as a way to protect urban residents from the more frequent and more intense extreme weather events anticipated under climate change. But the consequence of this could be to make an even greater proportion of homes and commercial buildings fall outside of the regulations, and to reduce the potential for low-income urban residents to obtain or build legal housing by increasing their costs. Innovative work by architects associated with the Philippines Action for Community Shelter Initiatives has shown how a more flexible approach to structural building standards can lower the costs of housing by up to thirty percent while maintaining an acceptable level of safety, and increasing the ability of urban poor groups to access appropriate housing. One way of achieving this shift is for governments and low-income groups to agree on experimental areas in which new standards can be tested for their appropriateness and cost. Some new technologies – such as the use of Interlocking Compressed Earth Blocks (ICEBs) – show the potential for structurally sound buildings that use locally available materials at lower cost, but building regulations may not reflect these local realities or new technologies (Dodman and Mitlin 2009).

A second area is related to the consequences of identifying land as 'vulnerable' or at risk. The process of mapping hazards and labelling particular land sites as "at risk" can be contentious and may bring disadvantages to particular low-income settlements. In Khulna, Bangladesh, the presentation of risk maps led to heated discussions as to the particular outcomes of this labelling process. Land-owners were worried that the value of their land would be affected if it was seen to be at risk. Land classified as being at risk from climate change may also lead to calls for the removal of settlements of low-income groups from such land on which they have settled for many years. Wealthy landowners, local authorities, and more affluent urban residents may use 'vulnerability' as an excuse for displacing low-income groups and getting access to the land they currently occupy. The urban authorities in Nairobi, Kenya have identified land adjacent to river banks as being at risk from climate change and are using this as a justification for removing low-income residents from this location. The paper noted earlier how the city government in Surabaya had tried to evict those living in long-established low-income settlements along the riverside by claiming that they were responsible for polluting the river and causing floods by filling it with waste (Some, Hafidz and Sauter 2009).

In any expanding urban area, the occupation of unsafe land sites by the urban poor will continue, unless there are safer, affordable alternatives that are also well located in regard to income-earning opportunities. Households in two flood-prone squatter settlements in Dhaka were asked to consider the incentives that would encourage them to relocate to safer locations. Despite the extent and difficulty of their experience coping with floods, many residents felt that relocation was not feasible without considerable incentives — including free land, grants and long-term employment opportunities (Rashid et al 2004) So measures to increase the supply and reduce the cost of safe and well-located legal land and housing are an important part of facilitating climate change adaptation for the urban poor. The absence of such measures is a reflection of a broader set of social, political and economic forces that have been in operation for decades — if not longer. Identifying existing land or housing as 'at risk' should be the first step in providing appropriate alternatives, but this should be developed in consultation with those who are at risk, rather than displacing and disadvantaging this already vulnerable group. There are some good experiences in the Philippines with urban poor organizations (supported by the Philippines Homeless People's Federation) working with local governments to identify and acquire land sites to rehouse those who lost their homes from disasters that also allow them to rebuild on safe sites (see Reyos 2009). But it would have been better to identify the sites at risk before the disaster and if possible make these sites safe or if this is not possible, support those who live there to move to safer locations.

3.2.2 Informal Responses

Of course, individuals and households who live in settlements at risk from storms or floods take measures to reduce the adverse impacts. These include measures to protect their homes and possessions and measures to reduce their exposure to the hazards — for instance moving temporarily to safer sites. Understanding and supporting these individual and household responses to increase their effectiveness are an important part of climate change adaptation. A study of low-income households' adaptation to flooding in Indore (India) found well-developed temporary and permanent adaptations to flooding including raising plinth levels, using materials and furniture that resist flooding (for instance heavy beds that did not float) and ensuring that shelving and electric wiring are high up on the walls, above expected flood levels. The inhabitants had contingency plans for evacuation if needed — for instance, first the movement of valuables, the elderly, children and animals to higher ground (Stephens, Patnaik and Lewin 1996). But the success of these adaptation measures depends on the residents' capacity to anticipate flooding and climate change will often change the timing and the volume and speed of floodwaters.

Discussions with those living in informal settlements in a range of cities in Africa found similar responses (as illustrated in the quotes below) and also many residents commenting on the increased unpredictability of flooding (Douglas et al. 2008).

"When we see very dark clouds up the hills, we expect heavy rains to come. So we get ourselves prepared by transferring our valuable things on our very high beds which are reached by climbing ladders. Also children who sleep on the floor are transferred to the high beds." Mrs Fatu Turay, Kroo Bay community, Freetown, Sierra Leone (quoted in Douglas et al. 2008).

"As soon as the clouds gather I move with my family to Nima to spend the night there. When the rain starts falling abruptly we turn off the electricity meter in the house. We climb on top of our wardrobes and stay awake till morning …. Our furniture has been custom made to help keep our things dry from the water…. These measures are adaptive strategies as old as I can recollect" One woman in Alajo, Accra (quoted in Douglas et al. 2008).

Of course, the adaptations noted above are pragmatic responses to environmental hazards taken by individuals or households. Survival needs and economic priorities often conflict with environmental risk reduction. It is often access to income-earning opportunities that is the main influence on why urban poor groups settle on the most environmentally hazardous sites. This also means a large potential for measures to address such environmental hazards. The inhabitants of the settlements that often get flooded in Indore mentioned above want to stay there because the central location means they are close to jobs and markets for the goods they produce and close to health services and schools; most of the inhabitants also have strong family, kinship and community ties with other local inhabitants. The housing is also very cheap (Stephens, Patnaik and Lewin 1996). Similarly, the pavement-dwellers in Mumbai and the waste-pickers living around the Payatas garbage dump in Manila, along with thousands of other communities at risk, are there because of the access to income-earning opportunities these provide.

Anticipating and managing risk seldom presents simple choices, especially for those with inadequate incomes. Actions taken by households to limit their exposure to risk can result in substantial losses in income and security, with long term implications. Dercon points out that in research on risk management and household coping mechanisms, more emphasis has been placed on short term implications, ignoring the longer term consequences for the deepening of poverty. Often, "... the best that poor people can do is to make choices that perpetuate poverty via choosing low return, low risk portfolios of activities and assets"(Dercon 2007 page 18). The social implications of these decisions must also be considered. For instance, removing children from school in response to changing economic realities (for instance avoiding the cost of keeping children at school and getting the contribution that children can make to household income or to child-care for younger siblings) has obvious long term implications for the potential and productivity of those children, and for the larger society.

When flooding occurs, there are ad hoc individual short-term efforts to survive and to protect property – for instance making barriers to water entry at the doorsteps or ditches to drain water away, making outlets at the rear of the house so water coming in flows out quickly. Sometimes people share protective storage or accommodation on higher ground. Spontaneous community action to unblock drainage channels is relatively rare. So there is limited collective effort and no significant intervention from local government (Douglas et al. 2008, CLACC and IIED 2009). Action is needed at the local level to improve their options for emergency action and evacuation. They need help at the municipal level to improve drainage, to regulate developments upstream and elsewhere that increase flooding in their communities, and to give them greater security of tenure so that they can invest in making their homes more flood resistant. They need help at the national level; particularly to ensure that their needs are included in national disaster reduction plans and that these and other impacts of climate change are included in poverty reduction strategies. They also need international help to see that funding for adaptation to climate change is directed towards their problems (Douglas et al. 2008)

Thus many measures that could be considered as "autonomous adaptation" to climate change taken by households are creative and resourceful responses to difficult conditions undertaken with minimal resources. But these have the limitation that they cannot address most deficiencies in community infrastructure and services (which may be the main reason they are at risk). These need a collective response, either in terms of local populations developing a collective voice for negotiations with government for infrastructure and services or in terms of working together to address these deficiencies (although as discussed later, generally in successful adaptation initiatives, there is a combination of these).

There is also the issue of what autonomous adaptation cannot do. A high proportion of the urban poor in most cities rent accommodation and have little scope (or motivation) for improving the structure in which they live. A large proportion of those that do 'own' their home are discouraged from investing in improvements because of insecure or uncertain land tenure. And all low-income groups face obvious limitations in their capacity to invest in better housing.

Much risk-reduction depends on better community-wide infrastructure but a case study of 15 disaster-prone "slum" communities in El Salvador shows the difficulties of getting appropriate risk-reduction action this level. Households recognized the serious risk of flooding and landslides and took measures to lower risks. But various factors limited the effectiveness of community-wide measures, including the individualistic nature of households' investments, the lack of representative community organizations and the lack of support from government agencies, with most residents viewing local and national governments as unhelpful or even as a hindrance to their efforts (Wamsler 2007). Of course, the motivation to form and sustain representative resident organizations in informal settlements is much reduced if there is little possibility of getting local governments or utilities to respond to their demands. In addition, many informal settlements have diverse populations with diverse interests that make it difficult to get broad-based community organizations. And, of course, many local governments see such community organizations as a political threat that they seek to contain in ways that limits the powers and effectiveness of these organizations.

3.3 Mobility and Migration

There is a need to understand migration as one in a range of strategies that individuals and households can use to adapt to climate change (Tacoli 2009). Rural to urban migration is often seen as 'a problem' by national and local governments and by development specialists. For instance, a review of the Poverty Reduction Strategy Papers in Africa showed how migration is seen as the cause of urban problems — putting pressure on urban areas, promoting the spread of crime and HIV/AIDS, stimulating land degradation and reinforcing both urban and rural poverty (Black et al. 2006). Many governments implement policies to try to slow rural to urban migration, yet most such measures have had little effect and often result in increasing hardships for the urban and rural poor. These negative perceptions of rural to urban migration go against the evidence that most such migration is the logical response by households to changing patterns of economic opportunity; for almost all nations, the scale of net rural to urban migration tracks the scale of the increase in the proportion of GDP generated by industry and services (most industries and service enterprises are in urban areas) and the scale of the increase in the proportion of the labour force working in industry and services (Satterthwaite 2007). Indeed, rural to urban migration is an essential part of any prosperous economy — and there is no high-income nation that is not predominantly urban and no successful economy that has not urbanized. In addition, remittance flows to rural families from those who migrate are an important part of their incomes and capacities to invest. Migrants are so often blamed for urban population growth (when natural increase and reclassification often contribute more to this than net in-migration) and for expanding illegal settlements (even though in many instances this expansion is mostly from long-time city residents).

This negative perception of migrants is firmly embedded in the discussions of climate change. Instead of seeing most migration as individual and household adaptations to changing circumstances, it is seen in terms of a failure or inability to adapt that leads to 'floods of environmental refugees'. There are predictions that by 2050 there will be as many as 200 million 'environmental refugees' – people forced to move by environmental degradation caused by climate change (Myers 2005, Stern 2006). These figures are also used to scare those in high-income nations, the implication being that most of these environmental refugees will try to move there.

This is not to suggest that climate change will not have very serious impacts on the lives and livelihoods of large sections of the rural (and urban) population, especially if global emissions are not reduced. But migration, mobility and income-diversification must be recognized as ways in which households adapt to changing circumstances to reduce their vulnerability to climate shocks and stresses (and other shocks and stresses). Migration is important for development. In many cases, mobility not only increases resilience but also enables individuals and households to expand and diversify their asset bases. So policies that support and accommodate mobility and migration are an important part of adaptation (and of development).

In many nations, the data available on migration flows are limited, especially in relation to internal migration, including the scale and nature of temporary and circular migration (which census data so often fails to capture). There are some studies that look at migration in response to environmental change and these can help inform a discussion of migration and climate change. Research in northern Mali in the late 1990s found that up to 80 percent of households interviewed had at least one migrant member, but this high level of mobility was related to economic opportunities and the need to diversify income sources, rather than the direct consequence of desertification and land degradation (GRAD Groupe Recherche Actions pour le Développement), 2001) Research in Burkina Faso suggests that a decrease in rainfall increases rural-rural temporary migration; migration to urban centres and abroad (which entails higher costs for those who move) is more likely to take place after normal rainfall periods and is influenced by migrants' education, the existence of social networks and access to transport and road networks (Henry et al, 2004). In Nepal, land degradation and environmental deterioration lead mainly to local movements, although the better educated tend to move to urban centres further away (Massey et al. 2007).

Thus, the limited research on the consequences of environmental degradation and extreme weather disasters suggests that these do not inevitably result in migration. Where they do, it is likely that movement is predominantly short-term, as in the case of disasters, and short-distance, as in the case of drought and land degradation. In the case of rising sea levels, much less can be inferred from past experience and the number of people forced to move will depend on their adaptation initiatives and on those undertaken by governments. The significance of non-environmental factors in migration, the uncertainty on the extent of changes in rainfall patterns and cyclone/hurricane frequency and strength as a consequence of climate change, and the fact that predictions only go as far as the next 50 years, are serious limitations for any realistic long-term assessment of the link between climate change and migration.

For slow-onset climate change that has negative impacts on agriculture in most low- and middle-income nations (including rising average temperatures and reduced water availability), income diversification and short distance circular migration are likely to be common responses. This will often have an urban component - for instance the movement of one or more family member to an urban area or temporary or seasonal work in urban areas. This kind of income diversification is likely to be an important element of climate change adaptation. It has proved very important for reducing rural poverty in many places. In China, a survey by the Ministry of Agriculture suggested in 2004 that non-farm incomes and internal transfers from migrants to urban centres were about to overtake earnings from agriculture in rural household budgets (Deshingkar 2006). In India, remittances account for about one-third of the annual incomes of poor and landless rural households (ibid). Earnings from non-farm activities are also substantial, and estimated to account for between 30 and 50 percent of rural household income in Africa, reaching as much as 80-90 percent in Southern Africa (Ellis, 1998), about 60 percent in Asia (ibid) and around 40 percent in Latin America (Reardon et al. 2001)

Remittances from urban household members and earnings from non-farm activities also have a major role in financing innovation and intensification of farming in Africa (Tiffen 2003) and in Asia (Hoang et al. 2005; Hoang et al. 2008). This includes providing the capital to invest in agricultural production – inputs, infrastructure, and sometimes waged labour. It also provides the safety net that enables farmers to take the risks inherent in changing long-held practices and is thus an essential element of agricultural adaptation to climate change. The extent of temporary, circular and seasonal migration and its contribution to rural households' income diversification is not generally recognized, although it is well documented in various studies (Guest 1998 for Thailand, Deshingkar 2006 for India, Hoang et al for Vietnam's Red River Delta, Zhu 2003 for China). In addition, many urban residents invest in rural property or keep rural assets (often managed by family members) as a safety net and rural safety nets were critical for many urban residents in Africa during the 1990s and facilitated urban to rural migration (Potts and Mutambirwa 1998).

Where climate change is causing environmental stress for rural livelihoods, it will be one among a number of factors in determining migration duration, direction and composition and these other factors (socio-economic, political and cultural) need to be integrated into adaptation policies. Agricultural adaptation initiatives should not assume that they ought to reduce out-migration, and especially rural-urban migration; indeed successful rural development often supports rapid urban development locally (as it generates demand for goods and services from farmers and rural households) and may even encourage rural-urban migration (Beauchemin and Bocquier 2004; Deshingkar 2004; Henry, Schoumaker, and Beauchemin 2004; Hoang, Dinh, and Nguyen 2008; Massey, Axinn, and Ghimire 2007). Thus, agricultural and rural development and the specific climate change adaptation actions that these need should not be linked to the reduction of migration.

There is also the potential role in adaptation of smaller urban centres. In most nations, a significant proportion of the urban population lives in urban centres with less than 20,000 inhabitants (Satterthwaite 2006). Small urban centres in agricultural areas can have especially important roles in the livelihoods of the poorest rural groups, often landless and without the means to migrate to larger cities, by providing access to non-farm activities that require limited skills and capital (Hoang et al. 2008). They also have an important role in the provision of basic services such as health care and education to their own population and that of the surrounding rural area, and this is likely to become increasingly important with both slow-onset climate change and the increase in frequency and intensity of extreme events. But little attention has been given to strengthening the competence, capacity and accountability of local governments in small urban centres, even though this would bring strong developmental advantages and increase adaptive capacity.

However, a failure to support rural populations to adapt will help produce crisis-driven population movements which make those forced to move very vulnerable. This is not the planned movement of an individual or a household to an urban centre helped by knowledge and contacts in that urban centre. A considerable proportion of the urban poor in some African, Latin American and Asian nations are refugees, fleeing wars and conflicts (including guerrillas and drug warfare) and disasters. Most of these crisis-driven movements may be unrelated to climate events but they show how much these destroy livelihoods and create vulnerable populations. A high proportion of these people move to urban areas, leaving behind homes, social networks, family ties and assets. It can take a long time to insert themselves into local communities (who may resent them as they compete for income-sources) and to build ties and participate in community organizations that can push for changes and negotiate with government and utilities for neighbourhood improvements. Ironically, it will be a failure of governments and international agencies to support the poorer and more vulnerable households to adapt (including that achieved by migration and mobility) and the failure of high-income nations to agree to the needed reductions in greenhouse gas emissions that will produce the crisis-driven migration that they currently fear.

4. ADDRESSING VULNERABILITY AND RISK: THE ROLE OF INSTITUTIONS, GOVERNANCE, AND URBAN PLANNING

It is impossible to conceive of an effective climate-change adaptation programme for any urban centre without a competent, capable local government that is able and willing to work with the inhabitants of the settlements most at risk — which in most nations means working with the residents of informal/illegal settlements. Adaptation has to be locally driven because hazards, risks and vulnerabilities are so shaped by local contexts. And the possibilities for their reduction are so shaped by the competence and capacity of local organizations and good use of local knowledge and resources. In most instances, this will also require representative organizations formed by the residents of the informal/illegal settlements and other groups particularly at risk to ensure that local government responses address their priorities and work to support the resources and capacities they can contribute. Local government has to provide the framework and policies that encourage and support the contributions of individuals and households and of a range of other local organizations including community-based organizations, non-governmental organizations (NGOs) and private enterprises. It also has to provide the needed local coordination for the actions and policies of different agencies from higher levels of government. The sections below focus on the roles of local governments and of community based organizations in adaptation. But these are both the groups that official development assistance agencies have most difficulties working with. No national government will want donor agencies to develop funding and support programmes for local governments outside of their control. Indeed, this would often include support to local governments from different political parties or orientations to those in national government. Or, even worse from their perspective would be funding channels to support the organizations formed by the residents of informal or illegal settlements. Even if national governments can tolerate new funding channels for these two key local actors, the official development assistance agencies lack the staff and structure to allow them to support the needed long-term, locally driven 'development+adaptation' processes in thousands of different urban centres (Satterthwaite et al. 2009). In many ways, the challenge of getting an international institutional framework capable of supporting locally-driven pro-poor adaptation is greater than the challenge of getting needed funding for it.

4.1 Local Government Responses

Within most local governments in low- and middle-income nations, there is generally little institutional capacity to address climate-related risks; and also a lack of accountability to citizens in their jurisdictions and little or no scope for citizen participation. This is even the case in cities in relatively prosperous middle-income nations — as illustrated by the earlier case study of Santa Fe. The long-evident lack of attention to the impacts of extreme weather on large sections of the urban population compounds the risks they face from the likely impacts of climate change. Climate change contributes another level of stress to already vulnerable populations, adding to the inadequacies in water and sanitation coverage, solid and liquid waste collection and treatment and pollution control — and of course adding to poverty and unemployment.

Thus, adaptation in urban centres that addresses the needs of low-income groups, and more generally the needs of vulnerable groups, is not possible without more knowledgeable, accountable, better resourced and technically competent local authorities that are willing and able to work well with the groups most at risk. Table 4 is a reminder of all the areas in which city or municipal government has important roles in reducing climate-related hazards or their impacts — in the built environment, in infrastructure and in services. They should also have key roles in adaptation that reduces impacts (including measures for pre-disaster damage limitation) and that helps with recovery after any disaster.

This is a point that has resonance far beyond the specific context of climate change: well-governed towns and cities have populations and economies that are resilient to a broader range of shocks and stresses. This includes the extreme weather and other events that can bring disasters that should have been avoided or whose impact could be much reduced. Well-governed urban centres also have above average performance on most indicators of health and quality of life. The most recent IPCC assessment emphasizes the adaptation capacity within well-governed urban centres (Wilbanks et al. 2007) — and well-governed urban centres should be able to protect their inhabitants from floods and storms and ensure a high quality of life by ensuring provision for infrastructure, services, public space, and by establishing a planning/land use management framework. They should be able to understand the very location-specific, place-specific local needs for this – through strong local information, careful consultation and accountable political and administrative systems. Planning, land use management and building and land use standards should ensure that sufficient land is available for housing (including low-cost housing) without urban expansion taking place over land that is dangerous or needed for city or region flood protection. This kind of adaptation strategy is something easily stated but almost always difficult politically. Well-governed urban centres can also incorporate measures to support mitigation into most of the policies mentioned above. Various cities in Latin America have also demonstrated a capacity to combine poverty reduction with policies that support city prosperity and with environmental improvements that benefit middle and upper income groups as well as low income groups (see for instance Menegat 2002; Velasquez 1998; Almansi 2009).

Local governments will often need to depend on cooperation with other local governments and/or support from higher levels of government to reduce climate-related hazards. For instance, urban centres facing floods from nearby rivers may depend on actions 'up-river' to reduce the volume and speed of peak flows. Local governments units within large metropolitan areas often face difficulties coordinating their responses to hazard reduction, especially where they are from different political parties or where their jurisdictions contain a concentration of middle and upper income groups reluctant to contribute to addressing wider city problems. Yet such coordination is often far more effective while also reducing costs.

There are very substantial synergies between successful adaptation to climate change and successful local development, including poverty reduction (Bicknell et al 2009). Reductions in poverty, including improvements in housing and living conditions and in provision for infrastructure and services, are central to adaptation. Successful, well-governed cities greatly reduce climate-related risks for low-income populations; unsuccessful, badly governed cities do not and may greatly increase such risks. One of the key predictors for resilience at the level of the individual, household and community is access to safe, secure housing with the necessary infrastructure and services. Oddly enough, the importance of safe, secure, adequate quality housing for adaptation is hardly discussed in the four IPCC assessments, despite its obvious importance in regard to protection from climate-related hazards — as well as being central to the health and often the income-earning possibilities and asset bases of low-income households. Perhaps the IPCC saw housing not as a government responsibility but as something provided by the market — forgetting the key role for government in providing the policies, regulations and infrastructure that are required in meeting housing needs and demands.

It is not surprising that most city governments and most ministries and agencies at higher levels of government in low- and middle-income countries have given little attention to climate change adaptation within their urban policies and investments. Even where city governments are competent, representative and accountable to poorer groups, they generally have more immediate pressing issues, including large backlogs in provision for infrastructure and services and much of their population living in poor quality housing. They are also under pressure to improve education, health care and security, and are looking for ways to expand employment and attract new investment. By contrast, climate-change related risks are uncertain and perceived as being in the future (see for instance Roberts 2008).

Unless adaptation to climate change is seen to support and enhance the achievement of development goals, it will remain marginal within most government plans and investments. Perhaps as importantly, the need for adaptation highlights the importance of strong, locally driven development that delivers for poorer groups and is accountable to them. The extreme vulnerability of large sections of the urban population to many aspects of climate change reveals the deficiencies

TABLE 4
The Role of Urban Authorities in the Four Aspects of Adaptation

Role for City / Municipal Government	Adaptation To Avoid Impacts	Pre-Disaster Damage Limitation	Immediate Post-Disaster Response	Rebuilding
Built environment				
Building codes	High		High*	High
Land use regulations and property registration	High	Some		High
Public building construction and maintenance	High	Some		High
Urban planning (including zoning and development controls)	High		High*	High
Infrastructure				
Piped water including treatment	High	Some	High	High
Sanitation	High	Some	High	High
Drainage	High	High**	High	High
Roads, bridges, pavements	High		High	High
Electricity	High	Some?	High	High
Solid waste disposal facilities	High	Some		High
Waste water treatment	High			High
Services				
Fire-protection	High	Some	High	Some
Public order / police / early warning	Medium	High	High	Some
Solid waste collection	High	High**	High	High
Schools	Medium	Medium		
Health care / public health / environmental health / ambulances	Medium	Medium	High	High
Public transport	Medium	High	High	High
Social welfare (includes provision for child care and old-age care)	Medium	High	High	High
Disaster response (over and above those listed above)			High	High

* Obviously it is important that these do not inhibit rapid responses.
** Clearing / de-silting drains and ensuring collection of solid wastes has particular importance just prior to extreme rainfall; many cities face serious flooding from extreme rainfall that is expected (for instance the monsoon rains) and this is often caused or exacerbated by the failure to keep storm and surface drains in good order.
Source: Satterthwaite 2008a.

in 'development', and unless these deficiencies are addressed, there is no real basis for adaptation. It is very difficult to conceive of how to get pro-poor and effective adaptation in nations with weak, ineffective and unaccountable local governments, especially where there are also civil conflicts and no economic or political stability. Many of the nations or cities most at risk from climate change lack the political and institutional base to address adaptation. It is also difficult to see how existing international institutions as they are currently configured can respond to the need for pro-poor adaptation. International funding for adaptation is still be far from adequate (Ayers 2009) but understanding how to make effective use of international funding to support the needed locally determined, locally driven needed adaptation that serves and works with those most at risk is even further off.

Of course, there are also many developmental interventions that have the potential to increase the resilience of low-income groups to climate change related stresses and shocks; indeed, almost any intervention that reduces poverty is likely to increase resilience and also to reduce the need for livelihoods and homes that bring high risk levels.

4.2 Community-Based Responses

For community-based adaptation, there is a danger that its relevance will be both overstated and underplayed at the same time. It will be overstated because community-based organization and actions cannot provide the citywide infrastructure and service provision and city–wide and city-region management that is central to adaptation. Many of the risks and vulnerabilities that low-income groups face are from deficiencies or inadequacies in infrastructure provision that they alone cannot address. For instance, they may be able to help construct or improve drainage (see the scale of what is possible in this in urban areas of Pakistan in Hasan 2006) and collect solid waste within their settlement (Anand 1999) but this needs a larger drainage and solid waste collection system into which to feed. Or investments and actions are needed 'upstream' from them — for instance, to reduce the volume and speed of floodwaters.

Low-income individuals and their families also face considerable structural adversity that constrains their capacity to act. They have to manage with very limited incomes and monetary assets in a social and economic context that is, in urban centres, dominated by money with commodified markets for labour and goods and services. As discussed earlier, there are often many constraints on the possibilities of organizing collective responses. In addition, those in power generally look down on low-income groups; even within democratic local governments, they are often seen as no more than vote banks. One of the consequences of this is that low-income citizens are not expected to be proactive citizens in part because they are judged to be less able than others in a multitude of ways.

But the relevance of community-based adaptation is also underplayed in that the policies and practices of governments and international agencies do not recognize the capacity of community-based organizations to contribute to adaptation or, if they do, they lack the institutional means to support them. Low-income urban residents can effect many risk-reducing measures, individually or collectively, while well-organized, representative community organizations are important for representing their interests to local governments and external funders. Also important is the possibility for these local organizations to form broader coalitions (or federations) to undertake work on a larger scale, and also to influence local and international views on effective adaptation and international strategies for adaptation financing. The national federations formed by slum and shack dwellers or homeless groups that are now active in at least fifteen nations and emerging in many others[10] have demonstrated a capacity not only to work at scale to improve housing conditions and basic infrastructure and services for their members — but also to form effective partnerships with local governments (Patel and Mitlin 2004; d'Cruz and Satterthwaite 2005; Mitlin 2008). These are the kinds of partnerships that can address deficits in infrastructure and services in ways that do address the needs of the most vulnerable groups and that are thus also central to climate change adaptation. These urban poor federations have also demonstrated their capacity to contribute to risk-reduction frameworks, especially in undertaking city-wide surveys of informal settlements and in detailed enumerations and mapping of informal settlements that provides the information base needed for upgrading (ibid; Weru 2004; Reyos 2009). Some federations have demonstrated a capacity to work with local authorities in resettling those living on high-risk sites (Patel et al. 2002).

There is also the key role of community-based organizations in post-disaster work, especially for those who are most affected, and this is often forgotten. Although the Indian Ocean Tsunami was not caused by climate change, the deficiencies in the post-disaster response despite (or perhaps in part because of) massive international funding show deficiencies that need to be understood and addressed, to ensure better responses in the future (ACHR 2005 2006). For instance, the survivors from this Tsunami in Banda Aceh were swamped by so much unregulated, uncoordinated aid (over 500 international organizations each with their own priorities, agendas and funds that needed to be spent quickly) that it undermined their social structures. Support for housing and infrastructure should have been entry points for helping the survivors get some control back of their lives including rebuilding homes and villages and strengthening their own social cohesion and self-determination. But the funding went to contractors with the construction seen as ends in themselves — and with no coordination (some

[10] see the website of Slum/Shack Dwellers International (SDI), http://www.sdinet.co.za/

TABLE 5
Examples of Asset-Based Actions at Different Levels to Build Resilience to Extreme Weather

Areas of Intervention	Asset-Based Actions		
	Household and Neighbourhood	**Municipal/City**	**Regional or National**
Protection	Household and community-based actions to improve housing and infrastructure Community-based negotiation for safer sites in locations that serve low-income households Community-based measures to build disaster-proof assets (e.g. savings groups) or protect assets (e.g. insurance)	Work with low-income communities to support slum and squatter upgrading informed by hazard mapping and vulnerability analysis Support increased supply and reduced costs of safe sites for housing	Government frameworks to support household, neighbourhood and municipal action; risk reduction investments and actions that are needed beyond urban boundaries
Pre-disaster damage limitation	Community-based disaster preparedness and response plans including ensuring early warning systems reach everyone, measures to protect houses, safe evacuation sites identified if needed and provision to help those less able to move quickly	Early warning systems that reach and serve groups most at risk, preparation of safe sites with services, organization for transport to safe sites, protecting evacuated areas from looting	National weather systems capable of providing early warning; support for community and municipal actions
Immediate post-disaster response	Support for immediate household and community responses to reduce risks in affected areas, support the recovery of assets and develop and implement responses	Encourage and support active engagement of survivors in decisions and responses; draw on resources, skills and social capital of local communities; rapid restoration of infrastructure and services	Funding and institutional support for community and municipal responses
Rebuilding	Support for households and community organizations to get back to their homes and communities and plan for rebuilding with greater resilience; support for recovering the household and local economy.	Ensure reconstruction process supports household and community actions including addressing priorities of women, children and youth; build or rebuild infrastructure to more resilient standards	Funding and institutional support for household, community and municipal action; address deficiencies in regional infrastructure

Source: Moser and Satterthwaite 2009.

households got two or more new houses or boats, others got none). The survivors also had to fight against a national government that wanted to create a 2 km construction free zone in which most of their homes and villages were located. So much funding was available at first (even paying people to attend meetings and clean their homes) that it undermined attempts to develop livelihoods and any role for community organizations. But then the funders withdrew, leaving communities with no source of income and no social cohesion. Despite the billions of dollars spent, poverty had not been addressed. To address these issues, 23 villages have been working together with the support of a small Indonesian NGO (Uplink Banda Aceh) to develop their own plans and priorities and to oppose the initiatives that threaten their homes and livelihoods (Uplink Banda Aceh and Sauter 2009). This is not an isolated case; indeed it is rare for those who are most impacted by disasters to be allowed central roles in designing and implementing responses (ACHR 2005 2006). Addressing this needs collective organization formed by those who survive. The Philippines Homeless People's Federation has been active in working with the victims of disasters and their local governments in developing responses that include upgrading and where needed resettlement on safer sites (Reyos 2009).

Table 5 below gives examples of the kinds of asset-based actions that households and community based organizations can take to build resilience to extreme weather and the ways in which this can be supported by local, regional and national governments.

5. CONCLUSIONS

How can governments and international agencies reduce the large and growing levels of risks being imposed by climate change on large sections of the urban (and rural) population in low- and middle-income nations? Most of those at risk have livelihoods and lifestyles that contribute very little to greenhouse gas emissions. Although there is a long history of richer groups reducing the environmental problems they face by transferring these to other people and other locations, climate change represents the largest and potentially the most catastrophic of these transfers.

For low- and most middle-income nations, clearly the priority is adaptation that addresses current and near-future risks and vulnerabilities, and the two key actors are local governments and the populations most at risk (and their organizations). Yet these are both groups that official development assistance agencies have difficulties working with. Development assistance agencies were set up to work with national governments and they lack the structure and staff to support the needed long-term local engagement with many localities. Most of the climate change risks evident in urban centres are related to development deficits — poor quality housing, inadequacies in provision for infrastructure and services and a failure of land-management to ensure that low-income households can find or build homes on safe sites. These are often underpinned by governments that refuse to address the needs of those living in informal settlements. This will not be addressed by new 'adaptation funds' that only support 'adaptation to climate change'. In effect, climate change adaptation in urban areas is not possible without building adaptation into development and without reducing the 'development deficit' in (for instance) provision for infrastructure and services (which may also be called the adaptation deficit). Climate change adaptation also requires more knowledgeable, accountable, better resourced and technically competent local authorities that are willing and able to work well with the groups most at risk. But the political and institutional means to achieve this are not easily conceived in most nations, especially on the time-scale needed for effective adaptation. In addition, even where local governments are more competent and accountable, unless adaptation to climate change is seen to support and enhance the achievement of development goals, it will remain marginal within most government plans and investments.

At a global scale, mitigation can be considered the most important contribution to adaptation, especially for all the cities, smaller urban centres and rural areas in low-income nations that have high risks and so little adaptation capacity. The difficulties in building local adaptive capacity, and the limits in external funders' knowledge of how to do so, adds greatly to the urgency of achieving global agreements that rapidly reduce total greenhouse gas emissions and avoid 'dangerous' climate change. But greenhouse gas emission reduction at the scale and speed needed to avoid this is unlikely, in large part because this necessitates substantial constraints on high-consumption lifestyles in high-income and increasingly in middle-income nations.

At national level, adaptation needs to be seen as a development issue, not an environmental issue; it also needs to be understood as an issue needing locally-driven development. Considering the issues raised above about local development, adaptation will require national frameworks and funding provisions to strengthen the capacity of local governments to act and to work with low-income group and other groups at risk. This is easily said but not easily achieved.

In many urban centres in low-income nations, a focus on mitigation, often promoted by northern-based initiatives, may serve to divert attention from the more pressing issues of building adaptive capacity, in full recognition of how climate change is likely to affect the urban and rural poor. It is also easier for international agencies to promote mitigation than to promote the much needed but messy, complex locally rooted process of pro-poor adaptation. It is strange to see 'mitigation' being included in projects that are meant to benefit low-income groups, when mitigation should be focusing on reducing emissions from middle- and upper-income groups.

Many of the inaccurate stereotypes imposed on the urban poor in discussions of development are being transferred to the climate change discourse. Instead of seeing migration and mobility as ways in which the poor adapt to changing circumstances (including climate change), the discourse is of "floods of environmental refugees". Instead of seeing the informal homes and neighbourhoods that house so much of the urban population as evidence of the capacity and ingenuity of low-income groups, and as a contribution to city development, these are usually seen as 'the problem'. Similar anti-poor attitudes are evident in government policies on the informal economy. Disasters usually have the greatest impact on low-income groups — and after disasters, at best, the survivors are seen as 'victims' in need of 'emergency relief,' under-playing the knowledge, resources and capacities they can bring to recovery and rebuilding. More generally, rural-urban migration is seen as 'the problem' yet this is overwhelmingly a rational response by individuals and households to the concentration of economic opportunity in particular urban locations. Urbanization is a necessary part of a stronger, more resilient economy; it is also not in opposition to rural development as urban to rural remittances, urban demand for higher value foodstuffs and urban support for off-farm and non-farm work support rural prosperity. Yet many national and local governments see urbanization as a problem — when the problem is their failure to change their governance structures to support it. The same is true for many official development assistance agencies who have long failed to understand the role of urbanization in development and failed to recognize the scale and depth of urban poverty.

References

ACHR (Asian Coalition for Housing Rights). 2005. *Tsunami; How Asia's Precarious Coastal Settlements are Coping after the Tsunami.* Housing by People in Asia 16. ACHR, Bangkok.

______. 2006. *Tsunami Update*. ACHR, Bangkok.

Afsar R. 2003. "Internal Migration and the Development Nexus: The Case of Bangladesh." Presented at "Migration, Development and Pro-Poor Policies in Asia," Dhaka, Bangladesh, June 22–24, 2003.

Alam, Mozaharul and MD. Golam Rabbani. 2007. "Vulnerabilities and Responses to Climate Change for Dhaka." *Environment and Urbanization* 19 (1): 81–97.

Aidoo, Magna and Trudy Harpham. 2001. "The Explanatory Models of Mental Health Amongst Low-Income Women and Health Care Practitioners in Lusaka, Zambia." *Health Policy and Planning* 16 (2): 206–13.

Almansi, Florencia. 2009. "Rosario's Development; Interview with Miguel Lifschitz, Mayor of Rosario, Argentina." *Environment and Urbanization* 21 (1).

Anand, P.B. 1999. "Waste Management in Madras Revisited." *Environment and Urbanization* 11(2): 161–76.

Asociación Civil Canoa. http://www.canoa.org.ar/DDHH02.html.

Avotri, Joyce Yaa and Vivienne Walters. 1999. "You just Look at Our Work and See if You have any Freedom on Earth: Ghanaian Women's Accounts of their Work and their Health." *Social Science and Medicine* 48: 1123–33.

Awuor C, Orindi V, Adwera A. 2008. "Climate Change and Coastal Cities: The Case of Mombasa, Kenya' *Environment and Urbanization* 20 (1): 231–42.

Ayers, Jessica. 2009. "International Funding to Support Urban Adaptation to Climate Change." *Environment and Urbanization* 21 (1).

Ayers J, Huq S. 2008. 'The Value of Linking Mitigation and Adaptation: a Case Study of Bangladesh' *Environmental Management* (Online): October 2008.

Bartlett, Sheridan. 2008a. *Climate Change and Urban Children: Impacts and Implications for Adaptation in Low- and Middle-Income Countries*. Human Settlements Discussion Paper Series, Climate Change and Cities 2. August 2008. London: International Institute for Environment and Development.

________. 2008b. "Climate Change and Urban Children: Implications for Adaptation in Low and Middle Income Countries." *Environment and Urbanization* 20 (2): 501–20.

Beauchemin, Cris and Philippe Bocquier. 2004. "Migration and Urbanization in Francophone West Africa: An Overview of the Recent Empirical Evidence." *Urban Studies* 41 (11): 2245–72.

Bebbington, Anthony. 1999. "Capitals and Capabilities: A Framework for Analysing Peasant Viability, Rural Livelihoods and Poverty." *World Development* 27: 2021–44.

Begum, Sharifa and Binayak Sen. 2005. "Pulling Rickshaws in the City of Dhaka: a Way Out of Poverty?" *Environment and Urbanization* 17 (2).

Berger L.R. and D. Mohan. 1996. *Injury Control: A Global View*. New Delhi: Oxford University Press.

Bhan, Gautam. 2009. "This is No Longer the City I Once Knew; Evictions, The Urban Poor and the Right to the City in Millennial Delhi." *Environment and Urbanization* 21 (1).

Bicknell, Jane, David Dodman and David Satterthwaite, ed. 2009. *Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges*. London: Earthscan.

Black, R., J. Crush, S. Peberdy, S. Ammassari, L. McLean Hilken, S. Mouillesseux, C. Pooley, and R. Rajkotia 2006. *Migration and Development in Africa: An Overview*. Migration and Development Series, Southern African Migration Project. Cape Town, South Africa and Kingston, Ontario.

Breman, J., M.S. Alilio, A Mills. 2004. "Conquering the Intolerable Burden of Malaria: What's New, What's Needed: A Summary." *American Journal of Tropical. Medicine and. Hygiene* 71 (2 supplementary): 1–15.

Bulkeley H., Betsill M. 2003. *Cities and Climate Change: Urban Sustainability and Global Environmental Governance*. London: Routledge.

Castles, Stephen. 2002. *Environmental Change and Forced Migration: Making Sense of the Debate*. Geneva: UNHCR.

CEPAL. 2003. Cited in Natenzon. 2006.

Chen, N. P. Valente and H. Zlotnick. 1998. "What Do We Know About Recent Trends in Urbanization?" In *Migration, Urbanization and Development: New Directions and Issues,* ed. Richard E. Bilsborrow, 59–88. New York: United Nations Population Fund.

Christoplos, Ian, John Mitchell and Anna Liljelund. 2001. "Re-framing Risk: The Changing Context of Disaster Mitigation and Preparedness." *Disasters* 25 (3): 185–98.

Cilento Sarli, Alfredo. 2007. *La vulnerabilidad urbana de Caracas.* http://168.96.200.17/ar/libros/venezuela/rvecs/3.2002/sarli.doc.

City of Melbourne. 2008. "Towards a City of Melbourne Climate Change Adaptation Strategy: a Risk Assessment and Action Plan Discussion Paper." Maunsell, Australia, July 2008.

CLACC and IIED. 2009. *Climate Change and the Urban Poor; Risk and Resilience in 15 of the World's Most Vulnerable Cities*. London: Capacity Strengthening in the Least Developed Countries for Adaptation to Climate Change (CLACC) and IIED.

Confalonieri U., Menne B., Akhtar R., Ebi K., Hauengue M., Kovats R., Revich B., Woodward A. 2007. "Human Health." In *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. Parry M., Canziani O, Palutikof J., van der linden P., Hanson C. Cambridge: Cambridge University Press.

D'Cruz, Celine and David Satterthwaite. 2005. *Building Homes, Changing Official Approaches: The Work of Urban Poor Federations and their Contributions to Meeting the Millennium Development Goals in Urban Areas*. Poverty Reduction in Urban Areas Series, Working Paper 16. London: IIED.

De Sherbinin, Alex, Andrew Schiller and Alex Pulsipher. 2007. "The Vulnerability of Global Cities to Climate Hazards." *Environment and Urbanization* 19 (1): 39–64.

Dercon, Stefan. 2007. *Fate and Fear: Risk and its Consequences in Africa.* Global Poverty Research Group, GPRC-WPS-074.

Deshingkar, P. 2004. "Improved Livelihoods in Improved Watersheds: Can Migration Be Mitigated?" Presented at ICAR-IWMI-ICRISAT International Workshop on "Watershed Management Challenges," New Delhi, November 3-4, 2004.

Deshingkar, Priya. 2005. "Maximising the Benefits of Internal Migration." Paper presented at the "Regional Conference on Migration and Development in Asia," Lanzhou, China.

Deshingkar, P. 2006. "Internal Migration, Poverty and Development in Asia." In *Asia 2015: Promoting Growth, Ending Poverty*. London, March 6–7, 2006.

Deshingkar, P., M. Deshpande, S. Kumar, A. Paradkar, L. Rao and P. Sharma. 2009. "Governance for Local Development in Small Towns: Addressing the Challenges and Opportunities of Increasing Migration and Mobility in India." Rural-Urban Working Paper 17, IIED, London.

Dodman D. 2009. In press. "Blaming Cities for Climate Change? An Analysis of Urban Greenhouse Gas Emissions Inventories." *Environment and Urbanization* 21(1).

Dodman, D. and .D Mitlin. 2009. "Victims to Victors, Disasters to Opportunities: Community Driven Responses to Climate Change in the Philippines." Paper prepared for World Bank Urban Symposium, Marseille, June 2009.

Dodman D. and D. Satterthwaite. 2008. "Institutional Capacity, Climate Change Adaptation and the Urban Poor." *IDS Bulletin* 39 (4): 67–74.

Domínguez Aguilar, Mauricio and Ana García de Fuentes. 2007. "Barriers to Achieving the Water and Sanitation-related Millennium Development Goals in Cancún, Mexico at the Beginning of the Twenty-first Century." *Environment and Urbanization* 19 (1): 243–60.

Dossou, Krystel and Bernadette Glehouenou-Dossou. 2007. "The Vulnerability to Climate Change of Cotonou (Benin): the Rise in Sea Level." *Environment and Urbanization* 19 (1): 65–79.

Douglas I., Alam K, Maghenda M., McDonnell Y., McLean L., Campbell J. 2008. "Unjust Waters: Climate Change, Flooding and the Urban Poor in Africa." *Environment and Urbanization* 20 (1): 187–205.

du Plessis, Jean. 2005. "The Growing Problem of Forced Evictions and the Crucial Importance of Community-Based, Locally Appropriate Alternatives." *Environment and Urbanization* 17 (1): 123–34.

Ellis, F. 1998. "Livelihood Diversification and Sustainable Rural Livelihoods." In *Sustainable Rural Livelihoods: What Contribution Can We Make?* ed. Diana Carney. London: DFID.

Enarson, Elaine. 2004. "Gender Matters: Talking Points on Gender Equality and Disaster Risk Reduction."

Enarson, Elaine and Lourdes Meyreles. 2004. "International Perspectives on Gender and Disaster; Differences and Possibilities." *International Journal of Sociology and Social Policy* 24 (10/11): 49–93.

Gentile E. and S. González. 2001. *Vulnerabilidad y gestión del riesgo por inundaciones en la ciudad de Buenos Aires: la cultura técnica de la imprevisión.* In Primer Encuentro: Adaptación de la Ciudad de Buenos Aires y el Area Metropolitana de Buenos Aires al Cambio Climático. Defensoría del Pueblo Adjunta de la Ciudad de Buenos Aires, November 14–15.

Giorgi F. 2003. "Variability and Trends of Sub-Continental Scale Surface Climate in the Twentieth Century. Part I: Observations." *Climate Dynamics* 18: 675–91.

Gouveia, Nelson, Shakoor Hajat and Ben Armstrong. 2003. "Socioeconomic Differentials in the Temperature–Mortality Relationship in São Paulo, Brazil." *International Journal of Epidemiology* 32: 390–7.

GRAD (Groupe Recherche Actions pour le Développement). 2001. *Potentialités et conflits dans les zones péri-urbaines: le cas de Mopti au Mali.* Rural-Urban Working Paper 6, IIED, London.

Greater London Authority. 2008. *The London Climate Change Adaptation Strategy*. Greater London Authority.

Guest, P. 1998. "Assessing the Consequences of Internal Migration: Methodological Issues and a Case Study on Thailand Based on Longitudinal Survey Data." In *Migration, Urbanization and Development: New Directions and Issues*, ed. Richard Bilsborrow. New York: UNFPA.

Hadley, C. and C.L. Patil. 2007. "Seasonal Changes in Household Food Insecurity and Symptoms of Anxiety and Depression." *American Journal of Physical Anthropology* (November 28) [epublication ahead of print].

Hardoy, Jorge E., Sandy Cairncross and David Satterthwaite, ed. 1990. *The Poor Die Young: Housing and Health in Third World Cities.* London: Earthscan.

Hardoy, Jorge E., Diana Mitlin and David Satterthwaite. 1992., *Environmental Problems in Third World Cities.* London: Earthscan.

Hardoy, Jorge E, Diana Mitlin and David Satterthwaite. 2001., *Environmental Problems in an Urbanizing World: Finding Solutions for Cities in Africa, Asia and Latin America.* London: Earthscan.

Hardoy, Jorgelina and Gustavo Pandiella. 2009. "Urban Poverty and Vulnerability to Climate Change in Latin America." *Environment and Urbanization* 21 (1).

Harvey D. 1996., *Justice, Nature and the Geography of Difference.* Blackwell, Oxford.

Hasan A. 2005. "The Political and Institutional Blockages to Good Governance: The Case of the Lyari Expressway in Karachi."*Environment and Urbanization* 17 (2): 127–41.

Hasan, Arif. 2006. "Orangi Pilot Project; the Expansion of Work Beyond Orangi and the Mapping of Informal Settlements and Infrastructure." *Environment and Urbanization* 18 (2): 451–80.

Hasan, A. and M. Raza. 2009. "Migration and Small Towns in Pakistan." Rural-Urban Working Paper 15. IIED, London.

Heflin C.M., K. Siefert and D.R. Williams. 2005. "Food Insufficiency and Women's Mental Health: Findings from a 3-Year Panel of Welfare Recipients." *Social Science and Medicine* 61 (9): 1971–82.

Henry, S., B. Schoumaker and C. Beauchemin. 2004. "The Impact of Rainfall on the First Out-Migration: A Multi-level Event-History Analysis in Burkina Faso." *Population and Environment* 25 (5): 423–60.

Héron D. 2006. *The TransMilenio Public Transportation System (Bogotá, Colombia)*. UNITAR/VEOLIA Environnement / UN-Habitat. http://www.sustainable-development.veolia.com/library/en/standalone/others/1767,Transmilenio-Bogota-ANG.pdf [accessed 31/3/09].

Herzer, Hilda and Nora Clichevsky. 2001. *Perspectiva histórica: las inundaciones en Buenos Aires.* In *Inundaciones en el Area Metropolitana de Buenos Aires,* ed. Alcira Kreimer et al. Washington, DC: World Bank.

Hoang, X. T., T. T. P. Dinh and T. H. Nguyen. 2008. "Urbanization, fruit production and rural livelihood transformations in the Mekong Delta." Rural-Urban Interactions Working Paper 14. IIED, London.

Hoang, X., N. Dang and C. Tacoli. 2005. "Livelihood Diversification and Rural-Urban Linkages in Vietnam's Red River Delta." Rural-Urban Working Paper 11. IIED, London.

Huq S., and J. Ayers. 2007. *Critical List: The 100 Nations Most Vulnerable to Climate Change*. Sustainable Development Opinion, December 2007. London: International Institute for Environment and Development.

Jiménez, Virginia. 2006. *Taller vivencial de intercambio de experiencias municipales en reducción deriesgos.* Report within the Framework of *Proyecto RLA/51467 Fortalecimiento Regional y Reducción de Riesgos en Ciudades Mayores de la Comunidad Andina.* Caracas, Venezuela, November 9–12.

Klein R., Huq S., Denton F., Downing T., Richels R., Robinson J., Toth F. 2007. "Interrelationships between Adaptation and Mitigation." In *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. Parry M, Canziani O., Palutikof J., van der linden P., Hanson C., 745–77. Cambridge: Cambridge University Press.

Kovats S., and R. Akhtar R. 2008. "Climate, Climate Change and Human Health in Asian Cities." *Environment and Urbanization* 20 (1): 165–75.

Manda, Mtafu A. Zeleza. 2007. "Mchenga — Urban Poor Housing Fund in Malawi." *Environment and Urbanization* 19 (2): 337–59.

Massey, D., W. Axinn and D. Ghimire. 2007. "Environmental Change and Out-Migration: Evidence from Nepal." Population Studies Center Research Report 07-615. Institute for Social Research, University of Michigan, Ann Arbor.

Mata, J. L. and Carlos Nobre. 2006. "Impacts, Vulnerability and Adaptation to Climate Change in Latin America." Background Paper presented at Regional Workshop on "Latin American Adaptation," UNFCCC, Lima, Peru, April18–20.

Mayor of London. 2007. *Action Today to Protect Tomorrow: The Mayor's Climate Change Action Plan*. Greater London Authority.

McGranahan G., Balk D., Anderson B. 2007. 'The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones' *Environment and Urbanization* 19 (1): 17–37.

McGranahan G., Satterthwaite D.. 2000. "Environmental Health or Ecological Sustainability? Reconciling the Brown and Green Agendas in Urban Development." In *Sustainable Cities in Developing Countries,* ed. Pugh C., 73-90. London: Earthscan.

Mejia, Fanny Y. 2000. *Construyendo una ciudad mas saludable y sostenible ambientalmente. Estrategia municipal para la superación de condiciones de vulnerabilidad del distrito central, capital de Honduras*. Seminar on *El Impacto de los Desastres Naturales en Areas Urbanas y en la Salud Publica Urbana en Centro America y el Caribe,* ASIES, Guatemala.

Menegat, Rualdo. 2002. "Participatory Democracy and Sustainable Development: Integrated Urban Environmental Management in Porto Alegre, Brazil." *Environment and Urbanization* 14 (2): 181–06.

Mitlin, Diana. 2008. "With and Beyond the State; Co-Production as a Route to Political Influence, Power and Transformation for Grassroots Organizations." *Environment and Urbanization* 20 (2): 339–60.

Montgomery, Mark R., Richard Stren, Barney Cohen and Holly E. Reed, ed. 2003. *Cities Transformed; Demographic Change and its Implications in the Developing World.* The National Academy Press (North America)/Earthscan (Europe): Washington, DC.

Moser, Caroline and David Satterthwaite. 2008. "Towards Pro-poor Adaptation to Climate Change in the Urban Centres of Low and Middle-Income Countries." Climate Change and Cities Discussion Paper 3. IIED, London.

Moser, Caroline and David Satterthwaite. 2009. Forthcoming. "Towards Pro-Poor Adaptation to Climate Change in the Urban Centres of Low- and Middle-Income Countries." In *People, Vulnerability and Climate: Understanding the Social Dimensions of Climate Change*, ed. Robin Mearns, Andy Norton and Edward Cameron. World Bank.

Muller, Anna and Diana Mitlin. 2007. "Securing Inclusion: Strategies for Community Empowerment and State Redistribution." *Environment and Urbanization* 19 (2): 425–39.

Murray, C. J. and A. D. Lopez. 1996. *The Global Burden of Disease: A Comprehensive Assessment of Mortality and Disability from Diseases, Injuries and Risk Factors in 1990 and Projected to 2020*. Boston: Harvard University Press.

Myers, N. 2005. "Environmental Refugees: An Emerging Security Issue." Presented at the "13th Economic Forum," Prague, May 23-27, 2005.

Natenzon, Claudia. 2006. *Inundaciones catastróficas, vulnerabilidad social y adaptación en un caso argentino actual. Cambio climático, elevación del nivel medio del mar y sus implicancias.* Paper submitted to "EMF Workshop IX: Climate Change Impact and Integrated Assessment,"Snowmass, Colorado, July 28–August 7.

Noticias de Latinoamérica. 2007. *Boletín de Agua y Saneamiento* 20, July 2007.

Patel, Sheela, Celine d'Cruz and Sundar Burra. 2002. "Beyond Evictions in a Global City; People-Managed Resettlement in Mumbai." *Environment and Urbanization* 14 (1): 159–72.

Patel, Sheela and Diana Mitlin. 2004. "Grassroots-driven Development: The Alliance of SPARC, the National Slum Dwellers Federation and Mahila Milan." In *Empowering Squatter Citizen; Local Government, Civil Society and Urban Poverty Reduction*, ed. Diana Mitlin and David Satterthwaite, 216–41. London: Earthscan.

Patel, V., R. Araya, M de Lima, A. Ludermir and C. Todd. 1999. "Women, Poverty and Common Mental Disorders in Four Restructuring Societies." *Social Science and Medicine* 49: 1461–71.

PlaNYC. 2007. *Inventory of New York City greenhouse gas emissions.* Mayor's Office of Operations, New York City.

Potts, Deborah. 2009. "The Slowing of Sub-Saharan Africa's Urbanization: Evidence and Implications for Urban Livelihoods", *Environment and Urbanization* 21 (1).

Potts, D. and C. Mutambirwa. 1998. "Basics are now a Luxury": Perceptions of Structural Adjustment's Impact on Rural and Urban Areas in Zimbabwe." *Environment and Urbanization* 10 (1): 55–75.

Pradhan, Elizabeth Kimbrough, Keith P. West, Joanne Katz, Steven C. LeClerq, Subarna K. Khatry, and Sharada Ram Shrestha. 2007. "Risk of Flood-Related Mortality in Nepal." *Disasters* 31 (1): 57–70.

Prowse M., Peskett L. 2008. *Mitigating Climate Change: What Impact on the Poor?* London: Overseas Development Institute, Opinion 97, April 2008.

Pryer, Jane. 1993., "The Impact of Adult Ill-Health on Household Income and Nutrition in Khulna, Bangladesh." *Environment and Urbanization* 5 (2): 35–49.

Pryer, Jane A. 2003. *Poverty and Vulnerability in Dhaka Slums; the Urban Livelihoods Study.* Ashgate, Aldershot.

Rashid, Harun, Len Hunt and Wolfgang Haider. 2004. "Urban Flood Problems in Dhaka, Bangladesh: Slum Residents. Choices for Relocation to Flood-Free Areas." *Environmental Management* 40 (1): 95–104.

Re, Mariano and Ángel Menéndez. 2007. *Impacto del cambio climático en las costas del río de la Plata.* In *Revista Internacional de Desastres Naturales, Accidentes e Infraestructura Civil 7(1),* April. Universidad de Puerto Rico, Recinto Universitario de Mayagüez, Puerto Rico. www.uprm.edu/civil/revistadesastres/Vol7Num1/2%20Re%20y%20Menendez.pdf.

Reardon, T., J. Berdegué and G. Escobar. 2001. "Rural Non Farm Employment and Incomes in Latin America: Overview and Policy Implications." *World Development* 29 (3).

Rebagliati, Ricardo. 2003. *Plan director de ordenamiento hidráulico y proyecto ejecutivo para el arroyo Maldonado del gobierno de la ciudad de Buenos Aires.* Contactar, Ciudades Saludables 11. www.revistacontactar.com.ar/plan_director_nro11.htm.

Renton, Alex and Robin Palmer. 2005. "A Place to Stay, a Place to Live; Challenges in Providing Shelter in India, Indonesia and Sri Lanka after the Tsunami." Oxfam Briefing Note, Oxfam International, Washington, DC.

Revi A. 2008. "Climate change Risk: An Adaptation and Mitigation Agenda for Indian cities." *Environment and Urbanization* 20 (1): 207–29.

Reyos, Jason. 2009. *Community-driven Disaster Intervention: Experiences of the Homeless People's Federation in the Philippines.* Manila and London: HPFP, PACSII and IIED.

Roberts, D. 2008. "Thinking globally, Acting Locally – Institutionalizing Climate Change at the Local Government Level in Durban, South Africa."' *Environment and Urbanization* 20 (2): 521–38.

Rogner, H, Zhou D., Bradley R., Crabbé O., Edenhofer O., Hare B., Kuijpers L., Yamaguchi M. 2007. "Introduction." In *Climate Change 2007: Mitigation.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate, ed. Metz B., Davidson O., Bosch P., Dave D. and Meyer L. Cambridge: Cambridge University Press.

Sarin, Madhu. 1991. "Improved Stoves, Women and Domestic Energy." *Environment and Urbanization* 3 (2): 51–6.

Satterthwaite, David. 2006. "Outside the Large Cities; the Demographic Importance of Small Urban Centres and Large Villages in Africa, Asia and Latin America." Human Settlements Discussion Paper Series, Urban Change-3. IIED, London.

_______. 2007. "The Transition to a Predominantly Urban World and its Underpinnings." Human Settlements Discussion Paper Series, Urban Change 4. International Institute for Environment and Development, London.

_______. 2008a. "Climate Change and Urbanization: Effects and Implications for Urban Governance." Paper presented at the United Nations Expert Meeting on "Population Distribution, Urbanization, Internal Migration and Development, Population Division," United Nations Secretariat, New York.

_______. 2008b. "Cities' Contribution to Global Warming: Notes on the Allocation of Greenhouse Gas Emissions." *Environment and Urbanization* 20 (2): 539–49.

_______. 2009. "The Implications of Population Growth and Urbanization for Climate Change." *Environment and Urbanization* 21 (2): 545–67.

Satterthwate, David, David Dodman and Jane Bicknell. 2009. "Conclusions; Local Development+Adaptation." In *Adapting Cities to Climate Change*, ed. Jane Bicknell, David Dodman and David Satterthwaite. London: Earthscan.

Satterthwaite, David, Saleemul Huq, Mark Pelling, Hannah Reid and Patricia Lankao-Romero. 2007. "Adapting to Climate Change in Urban Areas: The Possibilities and Constraints in Low- and Middle-Income Nations." IIED Working paper. IIED, London.

Some, Wawan, Wardah Hafidz and Gabriela Sauter. 2009. "Renovation not Relocation: The Work of Paguyuban Warga Strenkali (PWS) in Indonesia." *Environment and Urbanization* 21(2): 463–76.

Stephens, Carolyn, Rajesh Patnaik and Simon Lewin. 1996. *This is My Beautiful Home: Risk Perceptions towards Flooding and Environment in Low-income Urban Communities: A Case Study in Indore, India*. London: London School of Hygiene and Tropical Medicine.

Stern Review Team. 2006. *What is the Economics of Climate Change?* London: HM Treasury.

Tacoli, Cecilia. Forthcoming. "Climate Change and Migration." *Environment and Urbanization* 21 (2) (October, 2009).

Tibaijuka, Anna Kajumulo. 2005. *Report of the Fact-Finding Mission to Zimbabwe to Assess the Scope and Impact of Operation Murambatsvina*. United Nations.

Tiffen, M. 2003. "Transitions in Sub-Saharan Africa: Agriculture, Urbanization and Income Growth." *World Development* 31 (8): 1343–66.

UNDP–DIPECHO. 2007. *Proyecto regional de reducción de riesgos en capitales Andinas. Documento pais: Bolivia.* Mimeo, Brussels.

UN-Habitat (United Nations Human Settlement Programme) .2003a. *The Challenge of Slums: Global Report on Human Settlements 2003*. London: Earthscan.

________. 2003b. *Water and Sanitation in the World's Cities; Local Action for Global Goal.* London: Earthscan.

UN (United Nations). 2008. *World Urbanization Prospects: The 2007 Revision*. CD-ROM, (POP/DB/WUP/Rev.2007). New York: United Nations, Department of Economic and Social Affairs, Population Division.

________. 2009. *Global Assessment Report on Disaster Risk Reduction: Risk and Poverty in a Changing Climate*. Geneva: ISDR, United Nations.

Uplink Banda Aceh and Gabriela Sauter. 2009. "The Work of Uplink Banda Aceh." Local Organization Profile, Gatekeeper Series. IIED, London.

Valente, Marcela. 2007. *Cambio climático. Inundación Santa Fe: aguas violentas, desidia humana.* Buenos Aires, (IPS). http://www.proteger.org.ar/doc621.html. [Accessed April 2, 2007].

Van den Poel, E, O. O'Donnell, E. Van Doorslaer. 2007. "Are Urban Children Really Healthier? Evidence from 47 Developing Countries." *Social Science and Medicine* 65: 1986–2003.

Velasquez, Luz Stella. 1998. "Agenda 21; a Form of Joint Environmental Management in Manizales, Colombia", *Environment and Urbanization* 10 (2): 9–36.

Wamsler, Christine. 2007. "Bridging the Gaps: Stakeholder-Based Strategies for Risk Reduction and Financing for the Urban Poor." *Environment and Urbanization* 19 (1): 115–42.

Weru, Jane. 2004. "Community Federations and City Upgrading: The Work of Pamoja Trust and Muungano in Kenya." *Environment and Urbanization* 16 (1): 47–62.

WHO (World Health Organization). 2001. *The World Health Report. Mental Health: New Understandings, New Hope.* Geneva: WHO.

Wilbanks T. and Sathaye J. 2007. "Integrating Mitigation and Adaptation as Responses to Climate Change: A Synthesis." *Mitigation and Adaptation Strategies for Global Change* 12 (5): 957–62.

Wilbanks T., Romero Lankao P., Bao M., Berkhout F., Cairncross S., Ceron J-P., Kapshe M., Muir-Wood R., Zapata-Marti R. 2007. "Industry, Settlement and Society." In *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. Parry M., Canziani O., Palutikof J., van der linden P., Hanson C. Cambridge: Cambridge University Press.

Zhu, Y. 2003. "The Floating Population's Household Strategies and the Role of Migration in China's Regional Development and Integration." *International Journal of Population Geography* 9: 485–502.

CHAPTER 28

The Urban Poor's Vulnerability to Climate Change in Latin America and the Caribbean

Lucy Winchester,* Raquel Szalachman

1. INTRODUCTION

Latin America and the Caribbean (LAC) contribute a relatively small proportion to overall greenhouse gas (GHG) emissions on a global scale. The region's vulnerability, to global warming, however, is significant. LAC is a highly urbanized region, with urbanization levels rivaling that of many industrialized nations. UN projections suggest that 80 percent of Latin America will be urban by 2015. Although one out of three LAC inhabitants will live in small and medium-sized urban settlements, about one-sixth of the total population will be concentrated in nine metropolitan areas (ECLAC 2006). Cities in LAC currently face many environmental and sustainable development challenges, with significant impacts on human health, resource productivity/incomes, ecological "public goods", poverty, and inequity. In this context, climate change impacts in the region will exacerbate those development challenges.

Much of the urban population has limited adaptive capacity to environmental hazards, including climate variability and climate change, making large shares of the urban population vulnerable to increases in the frequency or intensity of storms, constraints on water supplies or food price rises. Particularly vulnerable to these impacts are the urban poor. The objective of this paper is to understand these impacts

*Corresponding author: Lucy.WINCHESTER@cepal.org

and their policy implications in LAC cities. Recent research shows limited explicit urban and local scale adaptation experiences for climate change impacts in the region (Winchester, 2008). Potential climate change impacts have not been found to be incorporated into regional and urban projects and initiatives as a conditioning agent.

This paper is based on an analysis of secondary data (quantitative and qualitative) from the United Nations Economic Commission for Latin America and the Caribbean (ECLAC). It builds on research results on urban poverty and precariousness in the region; on environmental and sustainable development issues in LAC cities; and ECLAC advances on overall climate change issues in the region. The approach is to first, characterize the urban poor, their habitat and relationship with the urban environment in LAC cities; second, hypothesize climate change impacts on the urban poor and their habitat; third, analyze LAC experiences in sustainable pro-poor habitat programs/policies for lessons learned; and lastly, develop a possible agenda for policy development in adaptation to climate change for the urban poor.

2. POVERTY IN URBAN AREAS IN LAC

Two out of three poor people in the LAC region are city dwellers. Urban poverty takes the form of low earnings due to precarious employment, lack of education and patrimonial assets. In urban areas, precarious living conditions, including lack of, or inadequate access to, sanitation and drinking water; insecure tenure arrangements; poorly constructed housing and overcrowded living conditions, are common to both poor and non-poor households. Social and spatial segregation of the poor is also a specific characteristic of LAC cities. Slums and informal settlements — including deteriorated inner city dwellings —are in many cities, the only option available for the urban poor.

Urban poverty is a multidimensional condition, subject to cultural, social and local influences, understood and experienced differently by the poor according to gender, age, ethnicity and capacities. Poor urban households share many characteristics with their rural counterparts (World Bank 2004 cited Wodon et al. 2001) notably household size, female or young household head, low levels of education, and unemployment of the household head and/or their partner. As for differences, returns to education are higher in urban areas than in rural ones, and while rural areas are characterized by self-employment, underemployment is prevalent in cities. Key attributes of city-specific poverty include: socio-economic vulnerability due to the urban poor's integration into the market economy (cash economy); socio-economic heterogeneity within urban areas; environmental and health risks specific to urban areas; socio-spatial segregation; social fragmentation, instability of networks, and violence; and insecure and deficient (in terms of quality) access to goods and services.

2.1 Income

While welfare (and consumption) measures focus on flows of income rather than the distribution of assets and opportunities, they provide an important basis for comparison of poverty incidence over time, and between places. In 2007, 34.1 percent of LAC's population was living in poverty (28.9 percent in urban areas), and 12.6 percent of these people were extremely poor, or indigent (8.1 percent in urban areas) (ECLAC 2008). Although poverty is proportionally lower in cities than in rural areas, the region's high level of urbanization has concentrated most of the population in urban centers.

The percentage of Latin Americans living in poverty conditions has fallen by 14 percentage points since the beginning of the 1990s, but it continues to be significant; 184 million poor and almost 68 million who are extremely poor. Much of the progress made in alleviating poverty and indigence in Latin America between 2002 and 2007 is attributable to growth effects. This is especially true in the countries that have achieved the highest percentage-point reductions in poverty. Nevertheless, the parts played by growth and distribution effects in the various countries of the region have differed, and improvements in income distribution have been the main cause of the reductions in poverty and indigence achieved in a number of countries (Bolivia, Brazil, Chile, Costa Rica, El Salvador and Panama) (ECLAC 2008).

During this same period, labor income accounted for most of the variation observed in the increase of average household income of lower-income groups (ECLAC 2008). Employment creation and increased labor productivity, especially among the poor, are the principal transmission mechanisms between economic growth and poverty reduction (Cecchine and Uthoff 2008).

In terms of relative poverty incidence, four country groups exist in the region: (i) where less than 25% of the urban population is poor (Argentina, Costa Rica, Chile, Panama and Uruguay); (ii) where between 25% and 40% of total urban population is poor (Brazil, Ecuador, Mexico, and Peru); (iii) where urban poverty fluctuates between 40% and 50% of the total (Bolivia, Colombia, Dominican Republic, Guatemala, and El Salvador); and (iv) where more than 50% of the total urban residents are poor (Honduras, Nicaragua, and Paraguay) (ECLAC 2008). In all countries where statistics are available, urban poverty levels are greater in secondary and smaller cities as compared to larger metropolitan areas (ECLAC 2008).

Income distribution is more unequal in Latin America than anywhere else in the world. The LAC region exhibits significant income inequalities in urban areas as well as at city level when compared to other regions in the world (UN Habitat 2008). Although conceptually related, poverty and inequality are two distinct phenomena and do not necessarily evolve together. In LAC although GDP per capita has grown in most of the countries, Gini coefficients showed an improvement only in some of them (see Table 1). In the long run, persistent inequalities may undermine efforts to reduce poverty. The average Gini coefficients for the region show levels up to 0.56 at the city level and up to 0.50 for urban areas (UN Habitat 2008), although there are some differences among countries. Brazil, Colombia and Guatemala exhibit extremely high levels of inequality at the urban level. At the city level, all 19 cities examined exhibit Gini coefficients above the International Alert Line[1], with Bogota and all the Brazilian cities analyzed showing the highest levels. Lesser unequal per capita income distributions between households, however, do permit increased reductions in poverty levels, given increases in average incomes per worker or increased state transfers.

TABLE 1
Change in Urban Inequalities (Gini Coefficient) and GDP Per Capita (Ppp) in Selected Countries

Country	Urban Gini Coefficient				GDP per Capita (PPP, Current $US, Country Data)			
	Year	Gini	% Change per Annum		Year	GDP per Capita	% Change per Annum	
Brazil	2005	0.60	-0.07	-	2005	8402	3.15	+
Chile	2006	0.52	-0.24	-	2005	12027	6.00	+
Colombia	2005	0.59	0.87	+	2005	7304	3.99	+
Ecuador	2005	0.51	0.69	+	1999	3419	1.73	+
Guatemala	2004	0.53	-0.37	-	2004	4401	3.39	+
Mexico	2005	0.50	-0.15	-	2005	10751	3.39	+
Uruguay	2005	0.45	-0.83	-	2005	9962	3.70	+
Venezuela	1994	0.48	0.30	+	2002	5449	1.23	+
El Salvador	2000	0.503	0.18	+	2000	5497	4.41	+
Honduras	1999	0.50	-1.06	-	1999	2725	2.18	+
Nicaragua	1998	0.53	0.19	+	1998	2802	4.09	+
Peru	1997	0.45	0.76	+	1997	4589	5.86	+

Data from various sources, mostly national household surveys between 1983 and 2005.
Note: Urban Gini Coefficient is for income.
Source: UN-HABITAT Global Urban Observatory 2008.

2.2 Public Services

In most of the LAC region, access to improved water and sanitation is quasi-universal. The increased growth of the urban population in the region, however, has created a huge pressure on the capacity of water and sanitation infrastructure and systems to continue to deliver adequate services. In 2004, 96 percent of the region's urban

[1]Gini coefficient values above 0.4, where inequalities have negative social, economic and political consequences (UN-HABITAT 2008).

households had access to safe drinking water and 86 percent to basic sanitation. In rural areas, access levels are 73 percent and 49 percent respectively. Less than 15 percent of the region's municipal wastewater is treated. While regional figures paint a positive image of the region, they mask the diversity of situations across countries, cities and parts of cities, as well as serious deficiencies in the quality and level of supply. According to World Health Organization statistics, in 2004, nine countries show coverage levels greater than regional averages (Argentina, Brazil, Colombia, Dominica, Mexico, Surinam, Uruguay, and Venezuela). Twenty-four countries show average coverage levels less than the regional average; in Haiti in 2004, just over nine percent of the total population living in urban areas had domiciliary connections to drinking water. Central American countries show a subregional average of 47 percent coverage (with household connections), while the Caribbean shows a subregional average of 49 percent. South America shows better performance levels (73 percent). Even in the countries where there is drinking water, supply services may be intermittent, and it is estimated that this corresponds to 60 percent of the population served thorough household drinking water supply connections (Winchester 2008).

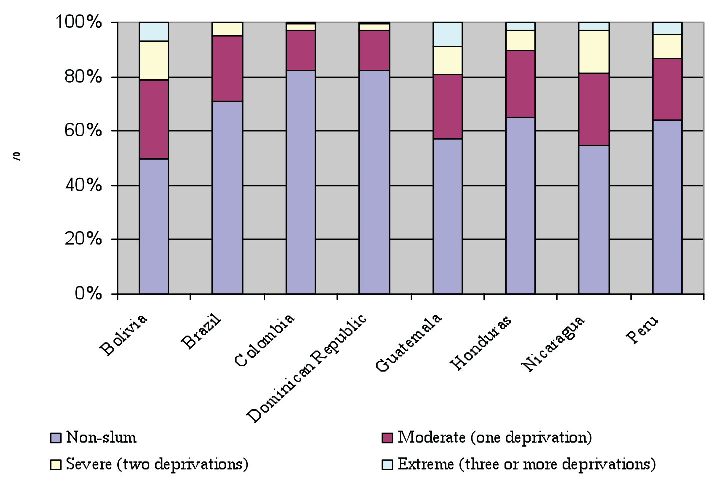
The majority of the persons without access to drinking water supply and sanitation services belong to low-income groups. Many of them are concentrated in periurban areas, principally in poverty belts on the periphery of many of the cities in the region. It has proven to be very difficult to provide these marginal areas with services of acceptable quality. The main problems encountered in efforts to expand services to marginal populations have been due, on the one hand, to the high poverty levels and the low level of payment capacity and culture, and on the other hand, to high construction and operating costs. These urban areas have very often experienced explosive growth and have developed in an unplanned manner, in areas far from existing infrastructure networks and with more difficult topographical conditions. This situation has meant that low-income groups, in many cases, must purchase water from private vendors at prices that far exceed (up to 100 times in some cases) those of official companies. These groups also incur a high health risk, as there is no guarantee of the quality of the water provided (Jouravlev 2004) or of the alternative solution adopted (collective sources, individual wells, illegal connections to networks, rainwater collection or extraction from nearby water sources).

2.3 Land Tenure, Poor Quality of Houses and Slum Formation

Studies by ECLAC showed that low-income households are willing to save mainly to acquire assets which are very valuable for them; among those, land is the most valuable asset held by the poor (Szalachman 2003). However, high land prices and lack of financial resources have given rise to irregular settlements, often on the periphery of cities. As a consequence, irregular tenancy and property insecurity are common to many cities in LAC. Nearly 50% of urban dwellers live in informal or illegal housing situations. Overcrowding is also prevalent; more than 30 percent of the urban poor population in nine out of 14 countries lives in overcrowded conditions: that is, three or more people to a room (Winchester 2006).

According to UN-Habitat, one out of every three people living in cities of the developing world lives in a slum. There are approximately 117 million slum-dwellers in the LAC region. Average slum prevalence in the cities of the region is 27 percent (UN Habitat 2008), although in Bolivia, Guatemala, Haiti and Nicaragua the concentration of slum households is very high (50.4, 42.9, 45.5, and 36.1 percent of total urban population respectively). In Brazil, almost 30 percent of urban population lives in slum conditions (accounting for over 45,000,000 persons). These slums cover a wide range of low-income settlements, from precarious dwellings in central districts to the informal settlements with inadequate infrastructure and facilities and overcrowding, located in risk areas and with different forms of tenure. Within these areas income levels are heterogeneous: for example, in Brazil, the non-poor comprise a significant proportion of residents of *favelas* to over 50% in some cities. The formation of slums in major cities has strengthened the processes of urban and social exclusion (often not just limited to access to the benefits the city offers but also to participation in the decisions affecting the city), exacerbated land use conflicts in urban development plans and impeded the process of improvement poverty conditions. Common to the majority of slums are also poor or inexistent basic sanitation, limited access to drinking water, and accumulation of waste and local dumps. Figure 1 shows the degree of shelter deprivation in slums for some countries. Bolivia, Guatemala and Peru show the highest proportion of extreme deprivation (meaning three or more deprivations).

FIGURE 1
Distribution of Slum Dwellers by Degree of Shelter Deprivation in Latin America (%)



Source: UN Habitat 2008, State of the World's Cities 2008/2009. Harmonious Cities. Earthscan: London. Figure 2.4.8A, p. 103, based on data from the Global Urban Observatory.

2.4 Health Care, Education and Social Security Benefits

These are three important sectors where social inequalities are particularly acute in Latin America. These inequities are characterized not only by specific population groups access to health, education and other social services, but also by the deficient quality of these services. Studies reveal that 70 percent of poor adults in urban areas have low levels of skills, as compared to 50 percent for the urban work force in its entirety. This is due to lower levels of education, but also to the poor quality of education and training to which the urban poor generally have access. Similarly, evidence suggests that differences in wages between different groups of people may be ascribed to levels and quality of education (Arias, Yamada and Tejerina 2003).

The region shows important deficits in health (an infant mortality level of 25.6 per 1,000 live births), education (around 25 percent of Latin Americans aged 15 and over have not completed their primary education), and in most countries where social security systems have been implemented, the systems are very regressive with the higher strata benefiting from better systems than lower income groups. This later group generally lacks access to social security due to limited public programs, unemployment, or labor informality (poor job quality, a lack of job security, low wages and a lack of access to social security). Women, again, overall show even more precarious access to social security. The proportion of workers with social security coverage as a percentage of the working age population is 25.5 percent for men, and 15.4 percent for women, according to ECLAC (2008).

ECLAC (2006 cited in Cecchine and Uthoff 2008) studies have detailed the links between the scarcity of human capital of active members of poor households, to their limited access to educational opportunities and the decisions of these families regarding their children's insertion in the educational system. Members of poor household have deficient educational levels, accessing precarious employment opportunities. Children and youth from these homes have few "quality" opportunities to educate or train themselves, this situation, combined with their lack social capital, limits them to accessing low productivity jobs in labor markets (ibid: 46).

2.5 Vulnerability

LAC is subject to extreme climatic events and natural phenomena that take place in frequently recurring cycles; these events and phenomena (earthquakes, tropical storms, hurricanes, floods, droughts, volcanic eruptions) and there is no evidence of their inclusion in urban planning and management (Winchester 2008). The region is highly vulnerable to these increasingly intense and frequent natural phenomena, which affect its ever more fragile ecological and social systems. The region's cities are extremely vulnerable to disasters of both natural and technological origin (the risks inherent in hazardous activities), with negative microeconomic and macroeconomic consequences at the local, regional and national levels. Moreover, urbanization patterns, especially among poor sectors (occupation of high-risk land, use of unsound materials), further heighten urban vulnerability. Vulnerability, in fact, is a critical dimension of poverty.

In LAC, the poor tend to settle in high risk areas in cities (geographically unstable environments) building their communities and homes with precarious materials. These low income groups are generally not covered by social security systems, and experience much more losses when natural disasters occur. Disasters of a more local nature, floods and landslides, as well as those affecting nations (hurricanes) disproportionately affect the urban poor in the region, for physical, social and economic reasons.

2.6 Employment

Low growth rates have had negative effects on employment and the creation of new jobs, particularly in urban areas. Nearly 40 percent of the urban population in Latin America is employed in low productivity sectors. Monthly labor income of urban workers in these sectors fell from US$345 to US$283 at 2000 prices between 1990 and 2006, widening the gap with formal-sector workers, whose income averaged US$ 493 in 2006 (ECLAC 2008). There is a high presence of large informal sectors and the persistence of underemployment among the poorest households. In 2006, informal workers in urban areas of Latin America accounted for 44.9 percent of all workers. Women are disproportionately represented within this sector. Women also receive lower wage incomes than men, given equal educational levels and experience (Cecchine and Uthoff 2008).

Joblessness in Latin America remains high, and as of 2006, the rate was still 2.4 percentage points higher than in 1990. Although some improvements were seen since 2002, sharp inequities still exist, with higher rates among the poor, women and youth.

Not all countries report the same level of wage employment, and such differences attest to the diversity of urban labor market conditions in the region. Three in every four urban employed people are wage earners in Argentina, Chile, Costa Rica and Mexico, closely followed by Brazil, Panama and Uruguay. In the Bolivarian Republic of Venezuela, Bolivia, Colombia, Guatemala, Honduras and Peru, however, only three or fewer out of every five employed people work for someone else. These countries also have a higher proportion of people employed in low-productivity sectors.

The current functioning of labor markets in the region prevents a large proportion of employed persons to live above, or beyond, the poverty line. ECLAC studies (for 2005) show that in urban areas in the region, between 10 percent (Chile) and 54 percent (Nicaragua and Honduras) of employed persons live in poverty conditions (Cecchine and Uthoff 2008).

According to the World Bank (2004), wage income represents 80 percent of total monetary income of the urban poor in Latin America. Integration into the market economy means that the urban poor are much more vulnerable to economic shocks than their rural counterparts, a situation that underscores the importance of the mechanisms of survival and adaptation of households, and understanding of the development of intervention strategies. Macroeconomic shocks are transmitted to poor urban households through the labor market. Consumption price effects can also be significant for the poor. For example, escalating food and oil prices triggered an upswing in indigence in mid-2008. Own account workers and those lacking in job security are the hardest hit when there are negative movements in the business cycle. This situation, combined with the heterogeneity of the urban area and its processes and business activities, make it complex and difficult to anticipate the effects of external shocks in the different social sectors. Although in 2005 about one third of total regional population lived in poverty (income measurement), the proportion of income vulnerable households is even much higher. In 2005, in not one of 16 major Latin American countries was the per capita average income of the fifth income decile equal to or larger than 2 times the poverty line (Cecchine and Uthoff 2008). Fifty percent of the population of Latin America is income vulnerable. In Argentina, Bolivia, Paraguay, Uruguay and Venezuela, 70 percent of the population is income vulnerable.

In many cities of the region, the urban poor inhabit formally (tenure) and work informally. Thus poverty is prevalent in formal neighborhoods created by public programs or through old invasions that were consolidated through combined public and community efforts. Those urban poor who work in the formal sector and inhabit formally are particularly vulnerable to economic cycles, both for the increased cost of living in conventional housing (with services "bought" in the market) and a relative increased rigidity in their asset mix.

This situation, combined with the heterogeneity of the urban territory and its processes and economic activities, makes it difficult and complex to anticipate the effects of external shocks to different social groups.

2.7 Social Exclusion, Social Risk, Violence

Maybe the worst consequences of the economic process of urbanization are the problems of social exclusion, social risk and violence. The social exclusion process closes the access of vulnerable people to the basic social structure that is needed for their human development. High levels of inequality usually menace social cohesion as they may lead to increases in crime and other forms of social and political conflict. These, in turn, create insecurity and lack of confidence among the economic agents which poses a further risk to economic growth and social development. Some studies have found a strong linkage between high levels of violence and lack of work and vice versa. These studies also found that in general, high rates of violence make mobility within the community dangerous, resulting in reduced access to education and lack of investment in communities (World Bank 2004).

Particularly acute in urban areas in the region is violence committed upon and by young people. Young people are over-represented in terms of incidence and gravity of violence, as both victims and perpetrators. Studies show that the incidence of violence among the causes of young people's deaths in Latin America is rising and has a strong gender bias: the rates for young men are more than double those for young women in deaths by homicide, traffic accidents and suicides (ECLAC 2008). Underlying this phenomenon is a marked material and symbolic social exclusion, reflected in inequality of opportunities, a lack of access to employment, alienation among young people who are not studying nor working, and the gaps between symbolic consumption and reduced material consumption. Other considerations include territorial segregation, and the lack of public spaces for social and political participation.

The persistence of inequalities due to social exclusion and difficulties in accessing social services and socio-political institutions has undermined efforts to decrease income inequality, and at the same time has increased group and individual vulnerability and has created poverty traps caused by the impossibility of social and physical mobility (World Bank 2004).

In Latin America, how the very poor perceive social inclusion reflects their aspirations for economic autonomy and material well-being, and their desire to possess the essential skills needed to get ahead in a knowledge- and information-based society. Perceptions and sensations of exclusion are stronger among the poor than among the non-poor. Feelings of loneliness, impotence and disorientation are most common among Latin Americans who live in lower-income households and have lower levels of education (ECLAC 2008).

2.8 Urban Environmental Degradation

Urban environmental degradation is a serious problem facing the region. Generally speaking, the causes of the increase in air, soil and water pollution in the region are associated with unplanned urbanization processes, agriculture (use of unsustainable techniques and agrochemicals) and poor environmental management. The uncontrolled growth of cities has exposed a large proportion of the population to deteriorating air and water quality, solid and hazardous waste contamination and coastal degradation. Overcrowding, lack of infrastructure and urban sprawl heighten exposure to pollutants, with the result that the poorest sectors are usually the primary victims of pollution. Usually poor neighbourhoods and slums are located near polluting industries or near rivers with polluted water due to industries residuals.

Inhabitants in Latin American cities are exposed to air pollutants that surpass recommended limits (Cifuentes and others 2005). In Mexico, approximately 25 million people are affected by air pollution. The evidence on airborne particulate matter and public health confirms the adverse health effects of exposure to urban pollution in cities throughout the world. The effects include respiratory and cardiovascular problems affecting children and adults, as well as susceptible groups. Malnutrition and lack of access to health services amplify the negative impact of air pollution.

Inadequate disposal of waste (including handling) is another direct and indirect environmental and social cost typical of urban poor communities. At a regional scale, 45 percent of all waste is disposed of in open-air dumps or waterways. In small cities this proportion reaches over 60 percent. In slums and marginal neighbourhoods, the consequences of using waste as a survival strategy are dramatic. Many slum families use waste as a survival strategy, via street collecting or scavenging in dumps, with the associated health risks.

3. CLIMATE CHANGE IMPACTS AND THE URBAN POOR IN LAC

The earth's surface temperature has increased between 0.74 and 1.8 degrees Celsius since 1906 (UN-Habitat 2008) but only in 2007 did the Stern Report and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) emphasize two important new elements: the human responsibility on climate change and the potential damage of climate change under different scenarios (ECLAC 2009). While cities are not the only generators of GHG emissions, there is no doubt that built-up areas consume more energy, producing more carbon emissions and therefore a larger contribution to climate changes than undeveloped areas.

Estimates by the United Nations Environmental Program (UNEP), indicate that in 2000, LAC was responsible for approximately 12 percent of global carbon dioxide emissions, with 4.3 percent of emissions coming from industry and 48.3 percent from land use changes (principally deforestation). Eighty-three percent of GHG emissions in LAC are from six countries - Brazil, Mexico, Venezuela, Argentina, Colombia, and Peru (UNEP/ROLAC and SEMARNAT 2006).

On a global scale, there is a strong correlation between emissions, population and GDP rankings, reflecting the importance of population and economic growth as emissions drivers. While this correlation holds true for LAC as well, overall drivers in the region include a rapid growth of energy consumption, substitution of other fuels for clean natural gas in the non-electricity sector and for electricity generation, low comparative advantages for alternative energy sources, serious air pollution levels in many urban centers, and continued deforestation. The LAC region suffers its consequences in a disproportionate way (ECLAC 2009), due to its geography, with numerous insular states located within the hurricane strip, and low coastal zones, or others depending on Andean defrosting for urban water provision, or subject to forest floods and fires. In most Caribbean island states, 50 percent of the population resides within 2 km of the coast (Vergara 2005).

Principally based on IPCC findings, this section presents an overview of the impacts of climate change for the region, especially for urbanization and the urban poor. While the IPCC global models are currently our principal source of understanding the global implications of climate change, these global models are not particularly useful for subregional and local analyses, due to regional diversities in topography and geography, as well as in relative sizes and characteristics of LAC countries. Global perspectives on regional impacts, however, do provide key elements for understanding the broad and profound implications of climate change for the urban poor.

Expected climate change impact at the regional level include increases in sea level, in surface temperatures, greater intensity of weather disturbances, tropical glaciers and snowcap melting, warming of moorlands and high altitude ecosystems in the Andes, greater frequency and extent of forest fires, the appearance of tropical disease vectors in the Andes piedmont, changes in agricultural productivity, and impacts on coastal and watershed ecosystems. Under certain scenarios, food insecurity could be significant.

Most of the region's largest cities are coastal cities and are vulnerable to sea level rise; many are very vulnerable to extreme weather events; and many Pacific Coast cities rely on glacial melt for their water supplies during dry summers — a source that will be severely depleted within 20 years at current rates of glacial melt. For example, the coastal plain of north-east South America is very low-lying, generating risks for major settlements from north-east Brazil to Venezuela. The coastal zone of Guyana holds 90 percent of national population and 75 per cent of the national economy; its highest point is 1.5 meters above sea level with much residential land, including the capital Georgetown, below high water sea level. In many Caribbean states, between 20 and 50 per cent of population resides within the low-elevation coastal zone (Satterthwaite and others 2007).

Vulnerability profiles in the region generally incorporate the multiple dimensions of development in the context of climate change and extreme events / disasters. These profiles do not recognize the urban poor's heightened economic vulnerability due to their dependency on cash incomes through an insertion in precarious labor markets. This reality is further complicated by price effects, in that access to urban services (water and sanitation, energy, transportation, health, and even education and childcare) depends on both the availability of quality services, and cash outlays by the poor. Access to housing (location, tenure and quality) also depends on cash income.

In the face of environmental change and extreme events, it is not clear how the poor manage these risks. Research shows that the poor diversify their asset portfolios to limit the impact of external shocks. They may combine these strategies with seeking new livelihood opportunities. Climate change complicates this situation. The poor, besides being affected disproportionately, are highly vulnerable to price increases that will exacerbate poverty conditions. It would be important for vulnerability profiles to incorporate the factors that transmit poverty to the vulnerable, such as precarious labor markets, the poor's insertion in the cash economy, education and health issues, urban economics and land use, property rights and tenure and how climate change may shift these factors in relation to the urban poor.

3.1 Water Resources

The LAC region, although basically humid, with large fresh water resources, presents difficulties in water availability and quality due to the irregular temporal and spatial distribution of resources. Stress on water availability and quality has been documented where lower precipitation and/or higher temperatures occur (IPCC 2007:586). During the last decades, important changes in precipitation and increases in temperature have been observed in the region. As a consequence of increased temperatures, the trend in glacier retreat is accelerating, and is a critical issue for Bolivia, Peru, Colombia and Ecuador, where water availability has already been compromised either for consumption or hydropower generation. The IPCC states that these problems with supply are expected to increase in the future, becoming chronic if no appropriate adaptation measures are planned and implemented. La Paz, Quito, and Lima will be particularly impacted.

The IPCC reports that by the 2020s, the net increase in the number of people experiencing water stress due to climate change is likely to be between 7 and 77 million. For the second half of the century, the potential water availability reduction and increased demographic pressures would increase these figures to 60 and 150 million (2007:583). Access to safe drinking water will become a concern for a greater proportion of LAC inhabitants.

Additionally, with respect to mountainous areas, among other expected changes, are a loss of many of the environmental goods and services provided by these mountains, especially water supply to urban areas, basin regulation, and associated hydropower potential.

The demand for water for irrigation is also projected to rise in a warmer climate, bringing increased competition between agricultural and domestic use in addition to industrial uses.

3.2 Extreme Events and Disasters

Many countries in the LAC region are at increased risk from natural disasters as a consequence of climate change. The region is subject to extreme climatic events and natural phenomena that take place in frequently recurring cycles — earthquakes, tropical storms, hurricanes, floods, droughts, volcanic eruptions — and the region is highly vulnerable to these increasingly frequent natural phenomena, which affect its ever more fragile ecological and social systems. According to UNEP studies (2003), in 70 percent of the area represented by Latin American countries, current vulnerability to flooding events is high.

Within the region the Caribbean is the sub region most affected by natural disasters. The entire region's cities are extremely vulnerable to disasters of both natural and technological origin (the risks inherent in hazardous activities), with negative microeconomic and macroeconomic consequences at the local, regional and national levels. ECLAC estimates that in the 2004 hurricane season, total economic impact of natural disasters in the region amounted to 7,559 million USD: and in 2005 season, to 5,409 million USD. Disasters also interrupt employment and may destroy employment opportunities, creating instability in income flows for the urban poor.

Estimations of future impacts and vulnerability to climate change show an important increase in the number of people at risk of hunger[2] and in the number of victims as a result of coastal floods, landslides and mudflows. For example, in 100 years the Rio de la Plata in Buenos Aires is expected to have average water levels of 60-100cm higher than today and stronger winds and storms surges. Within the metropolitan area, the zones most at risk are the low lying lands of the lower basins of the rivers, which have high concentrations of informal settlements (Satterthwaite and others 2007).

Experts on climate change sustain that the risk of extreme events such as floods, droughts and severe storms increases as global climate change escalates. For developing countries the risks come not only from direct exposure to natural hazards, but also from the vulnerability of social and economic systems to the effects of these hazards. This situation is much worse for low income inhabitants, usually living in high risk areas or in areas with lack of clean water, and a higher exposure to many diseases. According to ECLAC the cost of clean water has increased 10 times in the last century, and available reserves are diminishing dramatically (Jouravlev 2004).

Urbanization in itself may heighten urban vulnerability, especially among the poor. Urbanization worsens flooding because it restricts where floodwaters can go, as large parts of the ground are covered by roofs, roads and pavements, and

---

[2]According to studies summarized in the IPCC 2007, if the mean temperature rises a few degrees, output growth will lag behind growth in global food demand, sending food prices upward (IPCC 2007).

it obstructs natural channels (IDS, 2008). And as more people live in cities, even moderate storms produce dramatic flows. These have particularly disastrous consequences for urban settlements that lie less than 10 meters above sea level.

Poverty and vulnerability go hand on hand. The urban poor live in informal settlements without drainage systems and in poorly built homes. This makes them particularly vulnerable to the direct or indirect impacts of climate change. They can only afford to live in very risky zones and are usually unable to move or change jobs when a natural disaster is imminent. They are also least able to cope with illness, injury, and premature death, which may explain the rapid growth in the number of deaths and injuries from natural disasters, especially in Central America. For instance, Hurricane Stan in 2005 caused more than 1,500 deaths, while Hurricane Mitch in 1998 caused around 18,000. In Caracas, Venezuela, flash floods and landslides killed nearly 30,000 in 1999 (Zapata-Marti 2007).

In Latin America for instance, the coastal plain of north-east South America is very low-lying, generating risks for major settlements from north-east Brazil to Venezuela. The coastal zone of Guyana holds 90 percent of national population and 75 per cent of the national economy; its highest point is 1.5 meters above sea level with much residential land, including the capital Georgetown, below high water sea level. In many Caribbean states, between 20 and 50 per cent of population resides within the low-elevation coastal zone (Satterthwaite 2008).

3.3 Human Health

A warmer climate generally increases exposure to tropical diseases, health impacts from weather disturbances, and respiratory irritants. In Latin America, a large portion of the population lives in mountain ranges, including large urban areas situated above 2,000 m, normally not exposed to tropical diseases (dengue and malaria). Increased temperatures will most probably affect the prevalence of these vector borne diseases in higher altitudes. Diarrhoeal diseases also may increase as a result of more frequent and severe floods and drought. An increase in the frequency and severity of extreme weather events will result in more frequent humanitarian emergencies, particularly affecting populations in high-risk areas such as coastal zones, river valleys and cities. Climate change is also expected to lead to an increase of rodent-borne diseases: due to a warmer climate and changing habitats, allowing rodents to move into new areas.

Urbanization pressures have led to increased exposures of urban inhabitants to both traditional (infectious and transmissible diseases) and modern risks (chronic and degenerative diseases) in addition to those related to urban landslides and floods (IPCC 2007:587). The urban poor are disproportionately exposed to both traditional and modern risks. Within the group of urban poor, children are over represented, as poor families have higher dependency ratios than higher income families. Without adequate infrastructure and urban planning, poor dwellers that suffer from malnutrition, poor water quality and lack of sewage/sanitary services are exposed to all kind of diseases. Most of LAC has suffered in the last three decades numerous epidemics related to floods, for instance, most recently in Santa Cruz, Bolivia, dengue. According to the Bolivian Health Ministry, between December 2008 and February 2009 there were 50.000 cases reported only in Santa Cruz, and during that period of time there were some single days when 1.500 new people were infected (PAHO, 2009). Infants and elderly people are among the most vulnerable population, who are also less able to cope with heat waves or unable to move fast when a disaster is imminent. Due to lack of hospitals and medical facilities for low income population, this implies high mortality levels among the low income population.

Human migration due to drought, environmental degradation and economic reasons may also spread disease in unexpected ways, and new breeding areas for vectors may arise due to increasing poverty in urban areas (Simms and Reid 2006 cited in IPCC 2007: 601).

4. REGIONAL EXPERIENCES IN MITIGATION AND ADAPTATION

4.1 Adaptation

Adaptation for low income people must take into account pre-disaster adaptation to vulnerabilities, adopting measures like infrastructure improvements and reducing people's exposure by moving them to safer locations or improving their housing. Adaptation must also focus on reducing the impact of the hazard, for example, responding rapidly to flooding disasters. Finally measures should be implemented that reduce risks to likely future hazards, bearing in mind the uncertainty of their timing and magnitude.

As mentioned before, people in LAC cities are more vulnerable to extreme events due to climate change than those in wealthier and better governed cities, due to lack of resources or limited capacity of local or national governments to provide low income households with adequate infrastructure, and health services. Decentralization of responsibilities to urban authorities should have helped address these issues, but often it has not been accompanied by increased revenues or revenue-raising capacity. In most countries, the reform of the state during the 1990s weakened many of the mechanisms that support adaptive capacity as the state withdrew from public transport, health care and public works (Cetrángolo 2007).

The high proportion of informal settlements constitutes an additional source of vulnerability in the face of natural disaster. These settlements generally do not have adequate infrastructure or services, situation that often causes the failure of dams and the collapse of public facilities (hospital, schools, bridges and highways) during weather caused disasters. Better and more stable incomes, as well as improvements in education, health, land use regulation, urban planning, housing quality standards, water management and infrastructure investment could increase adaptive capacity.

On the other hand, the LAC region presents huge geographic differences among countries, from many small islands to large deserts, as well as tropical and still unexplored forests. The climate change impacts and the associated risks people will face, are very different depending on the geographic characteristics of the country. In coastal areas global warming has caused the sea level to rise and hurricanes and storms have increased in the last decades. In Andean valleys there has been a water shortage during periods of low rainfall, causing severe reduction in hydro-electric generation to the cities located in this region, together with huge increases in water availability and overflows, usually in spring, due to the melting of mountain snow. Whereas in tropical zones health diseases due to epidemics have increased in frequency, probably due to the increase in malnutrition and water pollution.

Geographic differences, the different sizes of the cities, and differences in income level and in income distribution also mean there is a great variation in the capacity and form in which LAC urban centers will adapt to the impacts of extreme weather events. There is evidence that some social indicators like adult literacy, life expectancy, and access to safe water have improved over the 1990s, but others contribute to limiting adaptive capacity such as high infant mortality, low secondary school enrolment, and high income inequality.

Some examples of autonomous adaptation especially in housing, such as improvement in design or quality, can be found in the related literature. Unfortunately most of the policy driven adaptation is through disaster response rather than reducing risks taking into account the factors that increase poor people's vulnerability. Probably one of the reasons is that governments and civil society have still not understood the magnitude and urgency of the problem, even though they have experienced the devastating impacts of current phenomena, with an increased number of victims from hurricanes and other extreme events.

Disaster risk reduction is an essential part of adaptation; it is the first line of defense against climate change impacts (Mitchell and Van Aaist 2008). A shift from disaster response to disaster preparedness and disaster risk reduction has not yet occurred in most city and national level policies, and without doubt this type of change would have significant relevance for improving urban resilience to climate change.

However, there are examples of urban governments that have key roles as risk reducers, providing necessary infrastructure and services, guiding settlements development and regulating industries, transport and other hazardous activities that can produce disasters. The work of La Red (the network of social studies for the prevention of disasters in Latin America) has shown how good urban governance is central to adaptation and how much it can reduce risks and vulnerabilities to extreme weather events.

Manizales in Colombia and Ilo in Peru are good examples of city governments taking steps to reduce vulnerability. Although neither of these local authorities was driven by climate change consideration, local governments took steps in order to avoid rapidly growing low-income populations settling on dangerous sites. Manizales was facing high rates or population growth and environmental degradation and from 1990 on local authorities together with private organization worked to develop programs to reduce risks, improve the living standards of the poor and regenerate ecological areas. In Ilo, although the population increased fivefold during 1960-2000, no land invasion or occupation of risk areas by poor groups has taken place, because local authorities implemented programs to accommodate the growing population in decent housing conditions (Satterthwaite and others 2007).

In Chile since 1998, The National Commission for the Environment has been working on a National Action Plan on Climate Change, which is structured around adaptation, mitigation and the creation and reinforcement of national capacities. In the National Strategy for Climate Change approved in 2006, the specific objectives for adaptation include: evaluation of the environmental, economic and social impacts of climate change, the definition of adaptation measures, and the implementation and follow up of these measures (Satterthwaite and others 2007).

In Mexico, in 1996, the government established a Fund for Natural Disasters (FONDEN) for post-disaster financing for reconstruction of public infrastructure and compensation to low-income producers for crop and livestock losses arising from natural disasters. FONDEN targets the beneficiaries and has limits to amounts it disburses per beneficiary. The intention is not to compete with private insurance. The government of Mexico is currently looking into the feasibility of obtaining financial reinsurance for FONDEN to cover its exposure from weather risks affecting the agricultural sector. In addition, providing catastrophic insurance coverage has encouraged the formation of mutual insurance funds amongst farmer organizations (Barnett et al. 2007).

Training poor dwellers to better understand climate risks and vulnerability will help reduce the impacts of natural disasters. In El Salvador, a new NGO called CESTA is trying to teach people to be aware of the dangers of climate change. In particular, it seeks to reduce low income people's vulnerability before flooding occurs. They teach people techniques for food conservation without refrigeration, for example, drying and salting meats, dehydrating fruits and vegetables, conserving, smoking and food burying. Indigenous farmers in some communities of the high Andes of Peru and Bolivia have been forecasting El Niño for at least 400 years, and are able to adjust their planting schedule if poor or late rains are expected. Their technique is to observe and study the changes in the Pleiades star constellation (Orlove et al. 2002).

4.2 Mitigation

The temperature increases associated with increasing concentrations of greenhouse gases will have mostly negative effects in both the LAC region, and at a global scale. The international community has reacted by agreeing to reduce the emission of greenhouse gases and stabilize concentrations at levels considered safe. Since the IPCC 2007, the seriousness of the global situation has become evident and additional commitments for reducing emissions will be negotiated in the short run. Contrary to previous rounds, developing country commitments for emissions reductions are required to cap total global emissions. Brazil and Mexico are two regional countries that have recently been included in the community of countries with official commitments to reduce emissions. International trade and investment conditions for carbon efficiency and neutrality are expected to dramatically increase in the near future, creating additional complexity for LAC countries. Pressures for the definition of mitigation goals and plans in the region are growing. This is particularly complex for the LAC region, given its strong dependency on primary natural resources extraction and use. The extensive biodiversity of the region and abundance of natural resource stock facilitated the development of sustainable development paradigms, although industry, transportation, massive tourism and urbanization have placed tremendous pressures on the regional environment.

Cities contribute to GHG emissions due to the vast quantity of energy they use as urban expansion goes on and also due to waste management practices. Climate change is closely linked to the increasing demand for energy and transport flows associated with urbanizations. Although cities continue to be in the background of the international debate on climate change, city governments can have a significant influence, especially through the facilities that they operate, and decisions on land use. Both have substantial impact on energy consumption levels, fuel used, and waste generated in the communities they serve (Winchester 2008).

There are few experiences in mitigation in LAC countries. In Chile the “Reduction of Greenhouse Gases” project began in March 1996 and its primary objective was to identify and apply energy efficient measures or renewable energy alternatives to reduce CO_2 emissions produced by the burning of fossil fuels. In Mexico, the Mexican Committee on Projects for Reducing Emissions and Capturing Greenhouse Gases was created in 2004 in order to participate in the Clean Development Mechanism, but it still lacks influence over the key actors that need to act for mitigation. In the Dominican Republic a reforestation project for the Sabana Clara has existed for 20 years, and the Dominican Government has declared some zones as protected areas. In Guyana de Climate Change Action Plan includes measures to mitigate climate change developing, applying and diffusing technologies that control, reduce or prevent anthropogenic emissions in all relevant sectors.

PROAIRE 2002–2010 is one of the overall strategies that integrate air quality and climate protection in Mexico City. It aims to cut emissions of air pollutants and greenhouse gases over an eight-year period. Activities include energy-efficiency improvements, protection of forests and green spaces, and public transportation enhancements. Many of the PROAIRE measures focus on transportation, which constitutes 37 percent of emissions within the federal district of Mexico City. In the region, the International Council for Local Environmental Initiatives (ICLEI), Cities for Climate Protection (CCP) campaign supports cities in the reduction of CO2 emissions, other GHGs and air pollutants. At a global level, the CCP Global Cities Network reduced 60 million tones of CO2 equivalent in 2005. In Latin America, for the 2005-2006 period, ICLEI reports energy savings of 8.5 million KWh, and 5,700 tons of CO2 equivalent/year mitigated, for a total of 18 cities participating at a regional level. The campaign offers a framework for local governments to develop a broad agenda on climate change, and provides analytical methods to help set reduction targets and develop a climate change action plan. Two examples of city specific implementation of improved technology are Sao Paolo (methane to energy) and Querétaro, Mexico (Street Light Retrofit) (Wyman 2006)

5. KEY LESSONS LEARNED FROM SUSTAINABLE PRO POOR HABITAT PROGRAMS IN LAC

Adaptation to climate change requires local knowledge, local competence and local capacity within local governments. It needs households and community organizations with the knowledge and capacity to act. It also requires a willingness among local governments to work with lower income groups. The key issue is how to build resilience to the many impacts of climate change that is strongly pro-poor, given the limited autonomous adaptive capacity of low income groups (Satterthwaite and others 2007).

Urban planning and management ensures planned adaptation. This means adjustments to building codes, land subdivision regulations and infrastructure standards combined with land use planning that restricts buildings in high risk areas and makes special provision for extreme events, including the use of insurance to spread risk. The problem is that this is more easily incorporated in new urban development areas, but there are restraints on implementation when huge parts of the cities correspond to informal settlements, and when financial resources are very limited.

In 2006, taking into account some of the thematic areas established in 1995 for the Regional Plan of Action for Human Settlements, the Regional Program for Social Housing and Human Settlements evaluated five programmatic areas as regards to successful policies for low income households: land, access to housing, and to public services, public space, and income generation.

These evaluations revealed that the programs with the best outcomes for low income dwellers were those that sought several goals simultaneously. For instance, to facilitate land access for low income groups through financial mechanisms, give them a house and at the same time help them access and achieve a better education: this scheme strengthened their capacity to access other kinds of credit funds in the future. Another finding was that creating employment not only helps with greater economic stability, but also increases disbursement capacity for future expenses and strengthens the sense of commitment and responsibility. Additionally, when people reach a new living standard they care for and pay more attention to the quality of private and public spaces.

These multipurpose programs demand important institutional agreements that may be very complex, and require an active participation not only from the national and local government but also from community, financial and business sectors, and even nongovernmental organizations. Although some countries of the region have implemented these types of programs, public policy is very deficient (insufficient regulation and active participation and social control, for example) in this area. Government policy has a key role regarding housing and urban policies and requires improvements in these areas.

Another important evaluation finding is the fundamental role that programs offering houses for different economic sectors within the same geographic area can have for social cohesion. These policies are very important in order to prevent and mitigate the exclusion or isolation in which many low income groups live, and allows them to get reach and participate in different urban realities (Simioni and Szalachman 2006).

With reference to specific policies, the evaluations demonstrated two successful policies in order to prevent illegal land occupation and to improve access to land for low income groups: improvement in tenure security and increases in urban land supply for low income groups. Argentina has developed two successful projects in this area: "Programa de Mejoramiento de Barrios" (PROMEBA) and "Programa Rosario Habitat" (ibid., 2006). There are also interesting programs in Colombia, METROVIVIENDA and USME, and tenure regularization programs in Bolivia and Peru. PROMEBA and Programa Rosario Habitat in Argentina have also been successful in securing access to basic services for low income groups. In El Salvador, due to the particular geographic characteristics of the county, the FUNDASAL program has adapted a special technology for sanitation.

As regards to improvement in housing quality and new housing construction, Chile has broad experience in building new neighborhoods though financial schemes that include savings, demand subsidies and mortgage credit. Unfortunately, due to the rise in the price of the land, many of the new neighborhoods are been built far away from city centers, with a high risk of exclusion for their population. Bolivia, Mexico and Paraguay have interesting programs for improving housing quality. Successful policies related to public spaces have strengthened infrastructure, like public transport in Bogota, or the Chilean community participation in roads paving. There are also some significant public patrimonial public space recovery programs in Chile and Ecuador. Argentina, Bolivia, Ecuador and Paraguay have some programs related to the development of productive activities to generate income and employment.

6. POLICY LESSONS AND CHALLENGES FOR ADAPTATION

Poverty reduction and sustainable development remain core global priorities, yet climate change must urgently be addressed. Economic growth alone is unlikely to be fast or equitable enough to counter the threats from climate change, particularly if this growth remains carbon-intensive and accelerates global warming. The success of any policy measure for reducing the poor's vulnerability to climate change impacts will also depend on the basic conditions into which it is inserted. Stable economies, with low levels of unemployment, and a positive rate of real growth are necessary preconditions to policy effectiveness and success.

LAC shows huge geographic differences among its countries: it is therefore very difficult to have a regional vision as regards to climate change and global warming. The Third Assessment Report (TAR) from IPCC stated that in most of Latin America there were no clear long-term tendencies in mean surface temperature, although some clear trends in warming in some areas and a few cases of cooling trends were observed (2001). These findings may explain the current low adaptive capacity of human systems in Latin America and why the region has still done very little in order to adapt or mitigate their economies to climate change.

Although it is difficult to have a regional vision due to huge differences among countries, some features are common. Urban centers concentrate enterprises and jobs. In most nations they account for 60-95 percent of economic activities. Therefore adopting measures in order to diminish natural disasters or climate change consequences is important for protecting economies as well as people. The potential losses from being unprepared and not having policies in place are too high to be ignored. Development and growth converge in urbanization: city dwellers generate an "urban footprint", and drive changes in land use and resource movements between rural and urban areas. Urban areas are concentrations of vulnerability to climate change impacts, as well as being major greenhouse gas emitters.

For hundreds of millions of urban dwellers, most of the risks from the impacts of climate change are a result of development failures, like the lack of capacity to provide infrastructure or adequate health services to the poor, especially in slums. Due to these development failures, people in poorer cities are much more vulnerable to events than the ones in wealthier and better governed cities, and adaptation requires addressing people's extreme vulnerability to climate change risks.

Sustainable development in LAC is as much threatened by the uncontrolled growth of the urban areas, and the growth of urban poverty and precariousness, as by urban environmental degradation. Any serious initiative to alleviate the negative impacts of climatic change must incorporate these closely knit, key links between the economic, social, territorial and environmental dimensions of development. It is also important to remember that this involves complex interactions of citizens, governmental and non governmental organizations, and business. As long as a large part of the population lives under the poverty line, without access to water and sanitation, without the minimum nourish requirements, and facing health problems, it is difficult to make them conscious of the consequences of climate change and the need for adaptation.

Adaptation to climate change should be seen as a part of development goals and be included within government plans and investments, in order to effectively design and implement pro poor and effective adaptation in LAC.

Adaptive capacity in LAC can be increased by better and more stable incomes for poor people. Due to its multiple dimensions, when we talk about climate change, the efforts need to go beyond the environment areas and include infrastructure, public services, and health and education areas.

National, local and urban governments have a key role as risk reducers for climate change not only by providing infrastructure and services, but also by guiding where development takes place and influencing where urban settlements should develop and what provisions should be taken in order to avoid disasters like floods, fires, etc. They should also establish adequate regulatory frameworks for land use and building standards in order to guarantee safer living conditions for poorer groups.

Governments should adopt disaster risk reduction measures concurrently. Limitations to this innovation exist, however: usually no data exists which clearly demonstrates the extent of the problem. The infrastructure needed to reduce risks is expensive, especially in informal settlements, and funds from international organizations or NGOs is usually available for post disaster relief and reconstruction, but not for risk reduction and development.

Mitigation measures can produce undesired impacts due to restrictions on commerce, and tax, dumping or tariff agreements. This can lead to changes in production patterns or transport policies that could be unaffordable for many LAC countries due to their low income levels. The present credit crisis adds more spillover effects for the underdeveloped world, due to the slower economic growth and the consequent implications for international trade, financial flows and commodity prices.

References

Arias, O., G. Yamada and L. Tejerína. 2003. "Education, Family Background and Racial Earnings Inequality in Brazil." *International Journal of Manpower* 25 (3–4): 355–74.

Barnett, B., C. Barret and J. Skees. 2007. "Poverty Traps and Index-Based risk Transfer Products" *World Development* 36 (10): 1766–85.

Cecchine, S and A. Uthoff. 2008. "Pobreza y empleo en América Latina: 1990-2005" *Revista de la CEPAL* 94 April: 43–58.

Cetrángolo, O. 2007. *Financiamiento municipal y combate contra la pobreza: ejes de análisis", Serie Medio ambiente y desarrollo, 134*. UN ECLAC, Sustainable Development and Human Settlements Division, Santiago.

Cifuentes, L. A., A. J. Krupnick, R. O´Ryan, and M. A. Toman. 2005. "Urban Air Quality and Human Health in Latin America and the Caribbean." Working Paper, October, Inter-American Development Bank.

ECLAC (Economic Commission for Latin America and the Caribbean). 2006. *Statistical Yearbook for Latin America and the Caribbean 2006*. Santiago: UN ECLAC.

__________. 2008. *Panorama social de América Latina 2008*. Santiago: UN ECLAC.

__________. 2009. *Cambio Climático y Desarrollo en América Latina y el Caribe, una reseña*. Project document. Santiago: UN ECLAC.

IDS (Institute of Development Studies), Sussex University. 2008. *Disaster Risk Reduction and Climate Change Adaptation: Closing the Gap*. http://www.preventionweb.net/files/7846_climatechange1.pdf

IPCC (Intergovernmental Panel on Climate Change). 2001. "Assessment Report on the State of Knowledge on Climate Change." In *Climate Change 2001: Impacts Adaptation and Vulnerability*. Cambridge: Cambridge University Press.

_______. 2007. "Summary for Policymakers." In *Climate Change 2007: Impacts, Adaptation and Vulnerability-Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Islam, R. 2004. "The Nexus of Economic Growth, Employment and Poverty Reduction: An Empirical Analysis." Issues in Employment and Poverty Discussion Paper 14. Geneva: International Labor Office.

Jouravlev, A. 2004. "Drinking Water Supply and Sanitation Services on the Threshold of the XXI Century." Serie Recursos Naturales e Infraestructura, 74. Santiago: UN ECLAC, Natural Resources and Infrastructure Division.

Mitchell, T. and M. Van Aaist. 2008. *Convergence of Disaster risk Reduction and Climate Change Adaptation: A Review for DFID*. http://www.preventionweb.net/files/7853_ConvergenceofDRRandCCA1.pdf

Orlove, B., J. Chiang and M. Cane. 2002. "Ethnoclimatology in the Andes: A Cross-Disciplinary Study Uncovers a Scientific Basis for the Scheme Andean Potato Farmers Traditionally Use to Predict the Coming Rains." *American Scientist* (September 2002). Also in: http://www.accessmylibrary.com/comsite5/bin/aml2006_library_auth_tt.pl?item_id=0286-25824482

PAHO (Pan American Health Organization). 2009. "*Situación actual del dengue en Bolivia" 6 de febrero, 2009.*

Justino, P., J. Litchfield, and L. Whitehead. 2003. "The Impact of Inequality in Latin America." Working Paper 21. Poverty Research Unit at Sussex, University of Sussex.

Satterthwaite, D. 2008. "Climate Change and Urbanization: Effects and Implication for Urban Governance." Prepared for United Nations Expert Group Meeting on Population Distribution, Urbanization, Internal Migration and Development, New York, January 2008.

Satterthwaite, D., S. Huq, M. Pelling H. Reid, and P. Romero. 2007. "Adapting to Climate Change in Urban Areas: the Possibilities and Constraints in Low and Middle Income Nations." Human Settlements Discussion Paper Series, International Institute for the Environment and Development. http://www.iied.org/HS/topics/accc.html. [Accessed April 2, 2009)

Simioni, D. and R. Szalachman. 2006. *Primera Evaluación del Programa Regional de Vivienda Social y Asentamientos Humanos para America Latina y El Caribe*. UN ECLAC, Sustainable Development and Human Settlements Division, Santiago.

Simms, A. and H. Reid. 2006. "Up in Smoke? Latin America and the Caribbean. The Threat from Climate Change to the Environment and Human Development." The Third Report from the Working Group on Climate Change and Development, The New Economics Foundation, August.

Szalachman, R. 2003. *Promoviendo el Ahorro de los Grupos de Menores Ingresos, Experiencias Latinoamericanas*. Serie Financiamiento del Desarrollo, 128. Santiago: UN ECLAC.

UNEP/ROLAC (United Nations Environment Programme, Regional Office for Latin America and the Caribbean). 2003. *GEO - Latin America and the Caribbean*. Mexico City: UNEP/ROLAC.

UNEP/ROLAC (United Nations Environment Programme, Regional Office for Latin America and the Caribbean) and SEMARNET (Secretaría de Medio Ambiente y Recursos Naturales). 2006. *El Cambio Climático en América Latina y el Caribe.* UNEP/ROLAC and SEMARNET.

UN-HABITAT (United Nations Human Settlements Program). 2008. *State of the World's Cities 2008/2009. Harmonious Cities*. London: Earthscan Publications.

Vergara, Walter. 2005. "Adapting to Climate Change: Lessons Learned, Work in Progress, and Proposed Next Steps for the World Bank in Latin America." Sustainable Development Working Paper 25, World Bank,Washington, DC.

Winchester, L. 2006. "Sustainable Human Settlements Development in Latin America and the Caribbean." Serie Medio Ambiente 99, UN ECLAC, Sustainable Development and Human Settlements Division, Santiago.

______. 2008. "Harmony and Dissonance between Human Settlements and the Environment in Latin America and the Caribbean." Project Document. UN ECLAC, Sustainable Development and Human Settlements Division, Santiago.

Wodon Q., R. Castro-Fernandez, K. Lee, G. Lopez-Acevedo, C. Siaens, C. Sobrado and J. P. Tre. 2001. "Poverty in Latin America: Trends 1986-1998 and Determinants." *Cuadernos de Economía* 114.

World Bank. 2004. "The Urban Poor in Latin America." Finance, Private Sector and Infrastructure Management Unit, Latin America and the Caribbean Region Report 30465, November 5, 2004. World Bank, Washington, DC.

Wyman, Michelle. 2006. "ICLEI, Local Governments for Sustainability." Presentation to IADB Sustainable Energy and Climate Change in Latin America and the Caribbean Seminar, November.

Zapata-Marti, Ricardo. 2007. "Information on Disaster Risk Management. Case Studies of Five Countres. Main Technical Report." UN ECLAC, Mexico City.

CHAPTER 29

Vulnerability and Resilience of Urban Communities under Coastal Hazard Conditions in Southeast Asia

Vilas Nitivattananon,* Tran Thanh Tu,
Amornrat Rattanapan, Jack Asavanant

Summary

Most coastal cities are facing complex inter-related problems associated with greater intensity and frequency of climate extremes. Often times these challenges require adaptation strategies that bring together comprehensive vulnerability assessments and implementation actions. The main objective of this paper is to apply the concept of vulnerability and resilience to coastal communities in Southeast Asia facing climate hazards. Southern Vietnam and Thailand are chosen as representative regions for the purpose of this study. The results show that flood risk has several consequences at different urbanization levels under increased climate variability. The main factors influencing the vulnerability of coastal communities are related to economics, institutional capacity, and the accessibility of knowledge for local community-based organizations.

*Corresponding author: vilasn@ait.asia

1. INTRODUCTION

Some of the key research priorities in Asia related to climate change are: impacts of extreme weather events (i.e. floods, storm surges, sea-level rise); identification of social vulnerabilities to multiple stressors during climate and environmental change; and adaption strategies concerning agro-technology, water resources management, and integrated coastal zone management (Cruz et al. 2007). All cities face risks from a range of natural and human-induced disasters, including disasters arising from extreme weather events, fires and industrial accidents. There can also be very large differences in the capacity of city authorities, households, and organizations to take measures to mitigate risk and ensure rapid, effective responses to disasters. Coastal hazards are most disruptive to settlements located in coastal and estuarine areas. Moreover, this is where a considerable proportion of the world's population lives. One estimate suggests that 60 percent of the world's population lives within 60 kilometers of the seacoast (Scott et al. 1996; Hardoy et al. 2001). Ports and other settlements located in coastal zones are also most at risk from any increase in the severity and frequency of flooding and climate change-related storms. The 2004 Indian Ocean tsunami, though not directly related to climate change, demonstrated that developing nations have limited capacities to independently marshal aid to recover from disasters. As a result, significant external assistance was required to augment national resilience to put affected nations on the sometimes lengthy path to recovery.

Coastal cities in Southeast Asia (SEA) will increasingly face complex inter-related problems associated with greater intensity and frequency of climate extremes. Impacts affect both urban and rural settlements along the coast including housing, infrastructure, and economic facilities. In some countries the impact of sea level rise has the potential to substantially affect human populations. One example is Ho Chi Minh City (HCMC) in Vietnam. This city in particular could potentially face serious inundation. In addition, coastal cities whose economies benefit from tourism, such as Phuket in Southern Thailand, may have considerable difficulties protecting tourist attractions and their economic base under hazard conditions. Table 1 illustrates major Southeast Asia disaster and their impacts during the twenty first century. According to the Asian Development Bank (2009), SEA countries have made significant efforts to build their adaptive capacity. However, there is still a need to practice more holistic approaches to building adaptive capacity and resilience to shocks. Without further mitigation or adaptation, Indonesia, Philippines, Thailand and Vietnam are projected to suffer a mean loss of 2.2% of GDP by 2100 on an annual basis, well above the world's projected average of 0.6%.

The main objective of this paper is to apply the concept of vulnerability and resilience to coastal urban communities under climate change hazards in SEA. We have chosen Southern Vietnam and Southern Thailand as representatives of the SEA region and will be focused on urban vulnerability to floods and tsunamis.

TABLE 1
Major Disasters in SEA during 2000s

Year	Country	Disaster Type	Population Affected	Number of Deaths	Houses Destroyed	Estimated Losses (million USD)	References
2000	Cambodia	Flood	750,618 (families)	347 (80% children)		150	ADPC (2003)
2000	Vietnam	Flood		1,044	1.6 million (affected)	300	ISDR (2005)
2000	Philippines (Manila)	Trash slide		224			ADPC (2003)
2001	Vietnam	All natural disasters		629	10,503	169	ISDR (2005)
2001	Philippines	317 disasters				190	ADPC (2003)
2002	Vietnam	Flash flood	200	53	60,463		ISDR (2005)
2003	Vietnam	All natural disasters		186	4,487	80	ISDR (2005)
2003	Philippines	Typhoon		1,000			www.scaruffi.com/politics/disaster.html
2004	Indonesia, Thailand, Myanmar, Malaysia	Earthquake, Tsunami	11,299k	174,592	157,393	7,904	UNESCAP (2008)
2005	Indonesia	Earthquake		1,500	14,640	400	www.scaruffi.com/politics/disaster.html
2006	Philippines	Mud slides		1,800			www.scaruffi.com/politics/disaster.html
2006	Indonesia	Earthquake	3,090k	7,432	205,057	3,314	UNESCAP (2008)
2007	Thailand	Flood	183,000	53		2	UNESCAP (2008)
2008	Myanmar	Cyclone (Nargis)	2,400k	133,655			UNESCAP (2008)
2008	Lao, PDR, Thailand, Cambodia, Vietnam	Flood (Mekong river)		184		193	UNESCAP (2008)

2. METHODOLOGY

In this paper, we provide an overview of hazard conditions in SEA coastal areas. Our analysis of urban development is based on reviews of studies and reports provided by national governments and international agencies.

In of the case of Southern Vietnam, HCMC in particular, the flood vulnerability assessments were conducted in two selected districts with different levels of urbanization. Both districts are located close to the Saigon River and are affected directly by river tides, climate change impacts, and rapid urbanization. An Environmental Assessment and Management tool was then used to determine appropriate adaptation strategies to flood risks in the context of integrated water resources management (Tu, 2009).

The second case presented in this paper involves coastal communities in Southern Thailand. Following the Indian Ocean Tsunami of 2004, housing and infrastructure were severely damaged. Additional impacts included serious effects on tourism, fisheries, and socio-economic development. This vulnerability assessment aims to identify appropriate adaptation tools and parameters for coastal disaster risk reduction. A multi-criteria method is also used in the vulnerability analysis for components of the built environment (Rattanapan, 2009).

3. CONCEPTS OF VULNERABILITY AND RESILIENCE

According to researchers Kay and Hay (1993), impact assessment methodology and risk reduction response can be divided into two fundamental measures: vulnerability reduction and resilience enhancement. The term "vulnerability" is used to describe the attributes of a system which will react adversely to the occurrence of external or internal stresses. The term "resilience" is used in the opposite sense to vulnerability — resilient attributes of a system will typically reduce the impact of internal and external stresses. According to Dolan and Walker (2003), adaptive capacity is reflective of resilience, such that a resilient system has the capacity to prepare for, avoid, moderate and recover from climate-related risks and/or change. Communities that are structurally organized to minimize the effects of hazards, whilst being able to recover quickly by restoring socio-economic vitality are thus, resistant and resilient. For the purpose of this study, resilience is measured by two aspects of peoples' livelihoods: 1) the assets they possess; and 2) the services provided to them by external infrastructure and institutions. Strategies to strengthen the resilience of communities should be based on the most effective combination of the two measures determined by local needs and capabilities (Prasad et al. 2009).

According to CSIRO (2006), adaptation is a risk-reduction strategy for ameliorating the adverse effects of climate change on human and ecological communities and for capitalizing on potential opportunities to do so. Specifically, climate change adaptation refers to actions, policies, and measures that increase the coping capacity and resilience of systems to climate variability and its impacts. Two types of approaches to "no regrets" adaptation include actions that reduce existing vulnerability and mainstreaming climate change and disaster into existing activities. Specific strategies for coastal communities include: identifying vulnerable areas, communities, and infrastructure; channeling future development around high, moderate, and low growth areas; developing coastal zone management plans; constructing new, or modify existing, coastal defenses; designing infrastructure to accommodate sea-level rise; and managing progressive retreat from the coastline. In addition, The World Bank (2007) suggests the following major interventions to address coastal urban adaptation: robust information systems, improved structures, energy efficiency, building standards, and planned development.

4. OVERVIEW OF COASTAL HAZARD CONDITIONS IN SOUTHEAST ASIA

4.1 SEA Development Context

According to Dick and Rimmer (2003), SEA has historically been the sea rather than the land. The Pacific Ocean, the Indian Ocean, and the Arabian Sea are each recognized as spheres of trade and cultural interchange. SEA has an immense length of coastline that enabled scattered populations to enjoy excellent accessibility with pre-modern marine technology. However, SEA has also been identified as one of the areas most vulnerable to global-climate-change scenarios now being put forward by scientists (World Bank 2007). Many of the region's estimated 500 million people live in either low-lying river deltas or far-flung islands that will be inundated if waters rise significantly. The most salient features of SEA's economic vulnerability have been the enormous rates of population growth and urbanization. By 2020, almost 56 percent of SEA's population is predicted to be urbanized (UN 2001). In 1995, the GDP of SEA was USD$ 633 billion, compared with 698 and 349 in China and Australia, respectively. SEA will have twelve urban agglomerations with populations over two million by 2015 (Dick and Rimmer 2003).

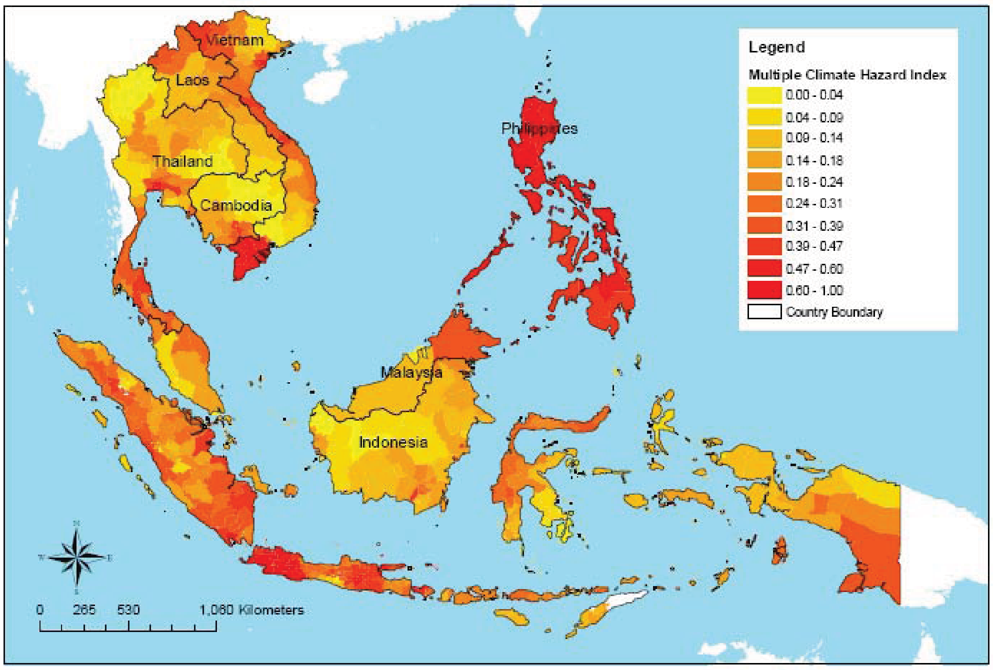
Four out of the 6 most populated countries in low elevation coastal zones are located in the SEA region. Vietnam has the highest percentage of their population located in Low Elevation Coastal Zones (LECZ), making the country especially vulnerable to the risks of climate change related sea level rise. Other SEA countries including Malaysia, Singapore, and Cambodia also have significant percentages of their populations located in LECZ.

4.2 Coastal Hazard Conditions and Urban Vulnerability

Based on IPCC reports (2007), more specific information about the nature of future impacts is now available across the regions of the world. Coastal areas, especially the heavily-populated megadelta regions in South, East and Southeast Asia, will be at greatest risk of impacts associated with increased flooding from the sea and, in some megadeltas, flooding from rivers. Compounded with rapid urbanization, industrialization, and economic development, climate change is projected to hinder the sustainable development of most developing countries in Asia. A comparative analysis conducted by Dasgupta et al. (2007) found that, among more than 10 developing countries in East Asia, the three countries most at risk from the urban impacts of 1 meter of sea level rise are located in SEA (Vietnam, Thailand and Indonesia, approximately 11, 2 and 2 percent of the countries, respectively).

SEA is one of the world's most vulnerable regions to the impacts of climate change because of its unique economic and social characteristics, long coastlines, and tropical climate. Additionally, the region's urbanization is among the fastest in the world and is occurring largely in coastal areas. With about 80% of the population living within 100 km of the coast this has led to a concentration of economic activity and livelihoods in coastal mega cities (ADB 2009). Figure 1 presents the overall climate hazard map in SEA with both climate-change related hazards (tropical cyclones, floods, landslides, droughts, and sea level rise) and hazard hotspots. The map includes the northwestern and Mekong regions of Vietnam, the coastal regions of Vietnam facing the South China Sea, Bangkok and its surrounding areas in Thailand, nearly all of the regions of the Philippines, and the western and eastern parts of Java Island, Indonesia (Yusuf and Francisco 2009). Understandably, most of the hazard hotspots are located in coastal zones. An example of the potential catastrophic damage that climate change could cause was exhibited during the December 2004 tsunami. Although the tsunami was not directly related to climate change, the event inundated and destroyed coastal settlements on Indonesia's Sumatra Island and illustrated the high vulnerability of coastal regions to disasters. The tsunami was a sudden shock that came without warning, it gave a geographic perspective to what could be anticipated under model scenarios of a more gradual increase in sea and river-delta water levels caused by climate change. However, the coastal effects of tsunamis will be altered somewhat by some climate change impacts including sea-level rise, trough increasing the risk of coastal inundation. Estuaries and harbors may also become more vulnerable to tsunamis as entrance channels deepen in response to greater tidal water volumes.

FIGURE 1
Multiple Climate Hazard Map in SEA



Source: Yusuf and Francisco 2009.

Based on ADPC (2003), floods from the Mekong River and its tributaries are the predominant hazard in Cambodia, Lao PDR and Vietnam during the monsoon season. In 2000, flooding cost about US$ 400 million in damages in these countries and Thailand. Disaster risks are exacerbated by siltation, deterioration of drainage and irrigation systems, and deforestation. Typhoons severely affect the Philippines and Vietnam as they move westward. La Niña increases the frequency of typhoons and their associated flooding. Additionally, the El Niño event of 1997-98 induced a drought cycle in Indonesia, causing widespread forest fires. Coupled with a protracted economic crisis, the fires adversely affected the country's food security. Indonesia and the Philippines, located in the Pacific Ring of Fire, suffer from earthquakes and volcanic eruptions. In countries like Indonesia and Vietnam, economic loss due to disasters can set back a decade of economic development. For Cambodia and Lao PDR, the effect is even worse, as scarce resources that could have been used for social and economic development are lost or spent on recovery efforts.

5. Case of Ho Chi Minh City

5.1 Background and Hazard Conditions

More than 30% of the population in Vietnam is made up of urban dwellers. According to Dasgupta et al (2007), Vietnam is one of the most vulnerable countries to sea level rise - approximately 10.8% of total population will be affected by a 1meter rise in sea level. Located in southern Vietnam, near the Mekong Delta River basin, HCMC is the largest and most rapidly developing city in the country. Projected global temperature increases of up to 3ºC suggest that sea level will increase by 50 cm by the year 2070 (ISDR 2005). HCMC is characterized by many rivers, arroyos and canals, from which the city is at risk from tidal process from the East Sea, and the Nha Be River. HCMC is especially vulnerable to flood risks because of its natural topography of flat, low land and because of increasing magnitudes of sea/river tides and rains. Moreover, the urbanization process in HCMC is rapidly increasing, putting pressure on infrastructure and services that limit resilience and the capacity to cope with flooding.

5.2 Vulnerability to Flood Risk

5.2.1 Data collection and Analysis

Two communities in District 2 and the Binh Thanh District were selected to assess vulnerability to flooding due to climate change and levels of urbanization. Key characteristics of the study districts are illustrated in Table 2. The two districts are located close to the Saigon River, and have been affected directly by river tides and other natural hazards in the past.

A Rapid Vulnerability Assessment (RVA) was conducted to collect data on social vulnerability (including human health and movement, housing and roads, transportation, and communication) and environmental vulnerability (including water resource quality and quantity, and sanitation). Moreover, the RVA provided information on residents' perceptions about the impacts of floods on their livelihoods, on their awareness about vulnerability to flood risks, as well as on their capacity to cope with and adapt to the impacts of floods and polluted water.

Secondary data collected by document review and individual interviews was coupled with primary focus group data. The focus groups consisted of structured interviews with residents in study areas via the RVA process. The goal of the interviews was to better understand resident awareness of regular and recent unexpected floods, their vulnerability and adaptation capacity to floods, and to determine what recent changes have taken place with respect to urban environmental management within their communities. Male and female residents were

TABLE 2
Key Characteristics of the Two Study Districts in HCMC

Characteristics	Unit	District 2	Binh Thanh District
Population	Persons	145,136	446,397
Population density	Persons/sq.km	2,917	21,674
Average household size	Persons	6	4
Annual household income	USD	100	250
Education (highest)	-	High school	University
Occupation	-	Commercial activities, small business	Commercial and industrial activities, industrial business
Total number of wards	Wards	11	20
Total Area	km^2	49.74	20.8
Total number of roads	Roads	120	290
Number of flooded roads	Roads	30	116
Total number of houses	Houses	30,000	110,000
Number of flooded houses	Houses	6,000	33,000

Source: Field survey in December 2008

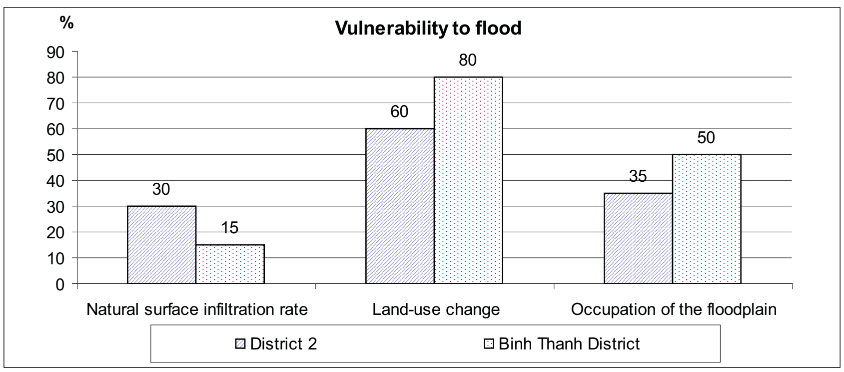
interviewed to ensure gender equity in getting information for the research. The fieldwork portion of our data collection was carried out over 5 days, in 40 households located in two communities: District 2 (Thao Dien Ward) and Binh Thanh District (Nguyen Huu Canh Street, Ward 22). The data collecting time was from 3pm to 6pm on Friday and Saturday to ensure that each household had representatives responding to the interview questions.

5.2.2 Comparative Assessment Results

The results from the RVA show that the study areas in Binh Thanh District and District 2 have the same flood risk characteristics in terms of meteorological factors. However, Binh Thanh District has less natural surface infiltration capacity and more channel networks than District 2. This makes Binh Thanh more vulnerable to flood and pollution than District 2.

In terms of anthropogenic aggravation of flood hazards, both communities have initiated land use changes. These changes include ground surface sealing by processes of urbanization and deforestation, increasing run-off ability, and sedimentation. While District 2 has changed from agricultural to domestic use, Binh Thanh District has increasingly used land for industrial and commercial activities together with existing domestic use. Most of the floodplain areas in the two districts have been occupied by informal houses and construction sites. Figure 2 presents the differences in flood vulnerability based on natural surface infiltration rates, land-use change (from agricultural to urban), and occupation of the floodplain. The results show that for these three indicators Binh Thanh District is more vulnerable to flooding than District 2.

FIGURE 2
Factors Affecting the Vulnerability to Flood in the two Communities

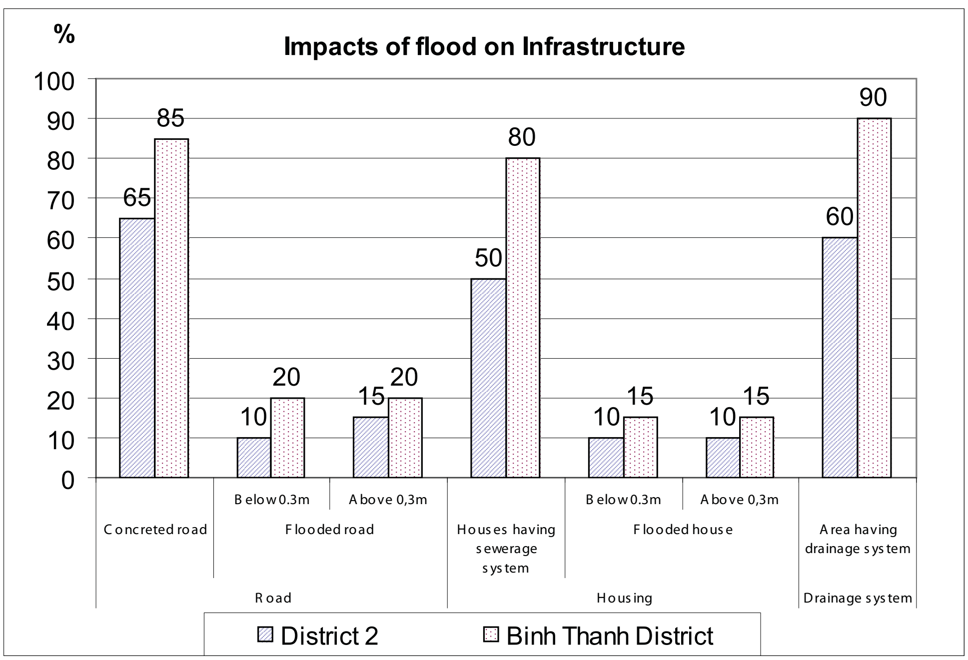


Source: Field survey in December 2008

Results from the RVA show that among the 100 existing flood points in HCMC, more than 25 points are located in the Binh Thanh District, with 30% of the population affected in 9 out of 20 wards. This is because most people in the district are middle class and poor - historically, they were living along canals and river banks. When the economy grew, the district grew into one of the region's most important industrial zones. As a result, more people migrated to the district, deforestation increased, and land became concretized, effectively reducing the natural infiltration capacity of the region. Day by day, under the impacts of increased urbanization and climate change, the region became more and more vulnerable to pollution and flooding. In District 2, 20% population has been affected by flooding in 7 out of 11 wards, and 10% of flood points in HCMC are in this district. Moreover, there are two different groups in District 2: poor people who have lived there for a long time and rich people from other regions who have recently bought land to build resorts and high-rise buildings. The recent urbanization that has occurred in the district has reduced the capacity of the natural environment to absorb shocks, and has caused inequity in facilities and services among residents. Poor communities with low qualities of living are more vulnerable to flood risks.

The impacts of flooding on infrastructure were also observed. The number of roads and land surfaces that are concretized, the number of households with sewage systems, and the number of areas with drainage systems are a few indicators for assessing vulnerability. According to results from the RVA, shown in Figure 3, the infrastructure in Binh Thanh District is more vulnerable to flooding than the infrastructure in District 2. Binh Thanh District will experience more road flooding below and over 0.3 m — the water level at which human transport and movement are obstructed while people are more vulnerable to polluted floodwater in terms of their properties, health, and also risk from electrocution. Although Binh Thanh District has more households with sewerage and drainage system, records show that more houses are at risk of flooding in the district rather than in District 2.

FIGURE 3
Impacts of Flood on Infrastructure



Source: Field survey in December 2008

From interviewing people in chosen communities in both districts, we gleaned different perspectives about the impacts of flooding on water quality and health. Rich communities have access to clean water from piped water supply systems, and they discharge their wastewater into sewerage systems, drainage system, and directly into the river. Poor communities tend to use water from wells (either protected or unprotected) and from rivers. They discharge their wastewater directly into canals and rivers and are more vulnerable to floodwater and pollution when flooding occurs. In some cases, the vulnerability of rich communities increases due to pollution caused by poor people. Since inundation in HCMC is due to urban flooding rather than flash floods, there is no need for residents to move to another place before a flood comes. However, people are not fully aware that they are more vulnerable to the pollution and health impacts of flooding. The results from interviewing 40 households in the two communities about their vulnerability to floods show very different levels of awareness and capacity between the two districts.

Overall, community perceptions about water quality and health risks are still lower than in the monitoring reports. This is because communities are not aware that polluted floodwater may be hazardous to their health. They observe that the color of the water is black or gray, or if it has a smell or not. However, they do not know details about potential sources of pollution within their living areas. The results show that both communities are vulnerable to water pollution because they have to face regular flooding events, however, there is a lack of access to health facilities necessary to mitigate vulnerability.

5.2.3 Current Adaptation Capacity and Approach

Residents of the communities we surveyed are aware that flood is regular phenomena they have to face. They also observe that blocked drainage systems make flood impacts more severe, and that the intensity and magnitude of floods has been increasing over time. Their most pressing concerns about flooding have to o with their property, and access to services and transportation rather than health impacts. Therefore, basic community adaptation solutions are focused on prevention and reduction of floodwater flowing into their houses by sand bags or concrete walls. Little adaptation measures are initiated to protect water resources. In general, individuals in the surveyed communities have limited adaptive capacity due to low awareness of the serious risks associated polluted flood water. Barriers to increasing their adaptation capacity are physical, social, motivational and attitudinal issues. These factors are interrelated and may increase the vulnerability of people to flood risk and water pollution. Table 3 presents the factors affecting adaptation capacity, as well as the vulnerabilities associated with the two survey districts. The major factors are occupation, traditional living culture, physical ability (gender, age), and their poverty (income).

TABLE 3
Community-Based Adaptation Capacity in the Study Areas

Factors	Community in District 2	Community in Binh Thanh District
1. Physical/Material factors		
1.1 Location	Both are located at low land area nearby the river bank (the Saigon River)	
1.2 Structure of buildings/houses	Simple structure of houses with concrete and 1 or 2 floors	Concrete houses with up to 3 floors with higher design standard
1.3 Extent and quality of infrastructure and basic services	Roads are paved with few drainage systems and drinking water supply	Roads are paved with sufficient but old water supply and drainage systems
1.4 Human capital	Low-income level of less than USD 100 per month (of main labor force)	Higher level of income of about USD 200 per month (of main labor force)
1.5 Environmental factors	Water in the canal is black, stinky, with oil layers on the surface. Lack of proper wastewater and solid waste management	Water in canal is also black and stinky. Although there are solid waste collection facilities, garbage still flows into canals
2. Social factors		
2.1 Family or kinship structures (weak/strong)	Women and children are most vulnerable because of their roles in the family. They are at home most of the time, and have to cope with inundation and pollution for longer periods.	
2.2 Gender and age	Women, the elderly and children have lower physical capacities to adapt.	
3. Motivational/attitudinal factors		
3.1 Attitude towards change	Most of people are aware that floods are natural phenomena. However, they do not pay much attention to changes in flood magnitudes, rainfall, or water levels.	
3.2 Awareness about hazards and consequences	People are not aware of the consequences and impacts of increasing magnitudes of rainfall, inundation and pollution in their communities. Therefore, they prioritize saving their possessions from possible damage rather than issues of health, sanitation and water supply.	

Source: Interview and focus group discussion (in December 2008)

5.2.4 Proposed Adaptation Strategies

In terms of adaptation to flood, there is a need to consider integrated water resource management, not only at city or district level, but also at the community level. Moreover, adaptation plans must vary from short-term to long-term strategies.

Based on the vulnerability and adaptation capacity assessments of HCMC and its residents to flood risks and water pollution, a suite of appropriate adaptation measures were chosen by using the Tool for Environmental Assessment and Management (TEAM) (Julius and Scheraga, 1999). TEAM employs a multi-criteria approach in evaluating adaptation actions and is careful to consider more than one factor when accessing the merits and drawbacks of each policy or strategy. The evaluation criteria used by TEAM are effectiveness, expense, environmental impacts, consistency, feasibility, urgency, and robustness/flexibility. The TEAM assessment identified and prioritized the following adaptation measures for the study area:

- Enhancing water efficiency and conservation/protection programs - to increase the efficient use of water and to reduce water pollution.
- Creating and improving floodwater and rainwater storage facilities - to reduce the water overflow and to reuse rainwater for irrigation and other utility purposes.
- Improving water treatment — to update and enhance wastewater treatment facilities, and to improve treatment regulation for industrial zones, buildings, and households before discharging wastewater into canals/rivers.
- Urban planning and infrastructure development – to consider flood risk in land use planning and design of new projects; to improve infrastructure (mainly road and drainage systems) to increase urban infiltration capacities and to decrease water runoff.

5.3 Findings

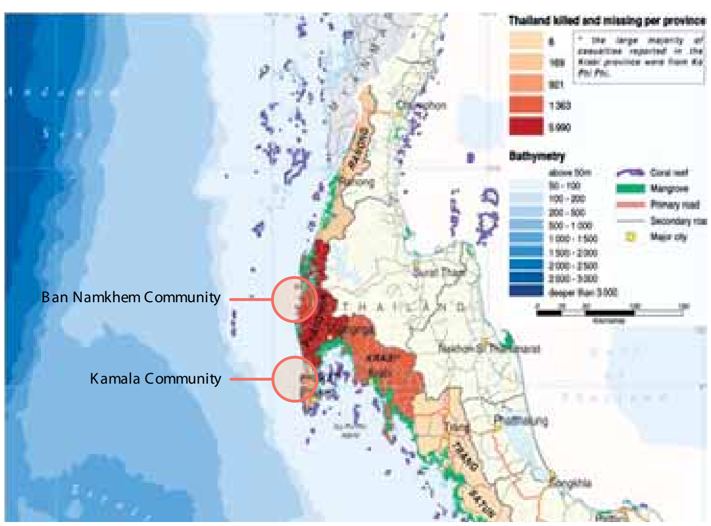
Residents in District 2 are vulnerable to floodwater in different ways that people living in Binh Thanh District. This is because the two districts have different levels of urbanization, infrastructure quality, and economic activity. At the individual scale, differences in vulnerability between the two districts depend on gender and age, attitudes and motivations, occupation and income, and living location and conditions. By using the TEAM tool, we were able to assess local adaptation processes by focusing on three main measures: determining and assessing vulnerability factors, identifying adaptation options, and assessing potential adaptation strategies.

6. CASE STUDY OF PHUKET AND PHANG NGA PROVINCES, SOUTHERN THAILAND

6.1 Background and Hazard Conditions

This case study involves community-level disaster vulnerability assessments using the earthquake and tsunami of 26 December 2004, as a reference point. The loss and devastation caused by the disaster brought suffering to millions of people around the Indian Ocean. Critical physical infrastructure and utility systems were severely damaged or destroyed. In the six affected provinces of Thailand, electricity, water supply, transport and communication systems were estimated to have experienced damages of USD 25.9 million, and revenue losses of USD 20.9 million (UNEP 2005b). The region experienced such high losses in part because communities and governments lacked proper disaster management plans. Robust vulnerability assessments are necessary for ensuring that communities are sufficiently adapted for future disasters. In this study, the housing and built environments of two fishing communities in Southern Thailand fishing were assessed for their vulnerability. Figure 4 provides the map showing the areas of the communities that were affected by the 2004 tsunami. Major demographic and economic characteristics of the two communities are illustrated in Table 4.

FIGURE 4
Affected Areas in Thailand by Tsunami 2004 and Location of the Selected Communities



Source: UNEP2005a

The first community, Ban Namkhem, has a primarily fishing-based economy. Some of the critical infrastructural vulnerabilities of Ban Namkhem include piers, schools and public open spaces, as well as vulnerable housing. Based on reviews of secondary data, key informant interviews and focus group discussions, the most vulnerable elements of the built environment are: the fishery port, the school, public open spaces, housing, road networks, and areas not reachable by the early warning emergency sound tower.

The second study community, Kamala, has been developing rapidly. It took a relatively short time for Kamala to recover from the tsunami. Due to the tourism growth in the province several hotels, houses, and service buildings have been developed along the beach. The community's most vulnerable housing and infrastructures are: large buildings (including residential, villas and hotel), small and medium buildings (including guesthouses, apartments, beach bars, tailor shops, small shops and restaurants), governmental office buildings (including police station, and medical clinic), school, and areas not reachable by the early warning emergency sound tower.

TABLE 4
Key characteristics of the two study communities

Characteristics, Unit	Ban Namkhem	Kamala
Population	5,060	5,003
Population affected by the Tsunami	4,200	2,500
Average household size	4	4
Total area, sq.km	62 (for whole TAO)	18.9
Annual household income, USD	330	515
Major religion	Buddhism	Muslim
Major education	Primary school	Secondary school
Economic base	Fishery, small business	Tourism, small business

Source: Field survey in December 2008

6.2 Vulnerability Assessment Results

6.2.1 Data Collection and Analysis

Primary and secondary data collection was conducted from December 2008 to January 2009. The primary data were obtained via the following methods:

- Unstructured interviews. Initial basic information on the communities was collected.
- Structured interviews. These involved the villagers, community leaders and community network group members, NGOs representatives, government officers, and local authorities.
- Survey questionnaires. This was random sampling of households in the specific areas.
- Field observations and photographs. This method collected information about physical conditions of existing buildings, critical infrastructure, and environment management.
- Focused group discussions. Four groups (two in each community) were formed for discussion exercises.

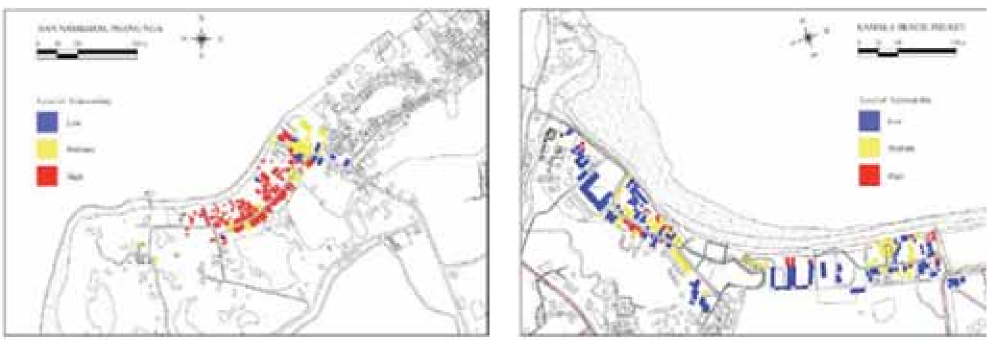
The results of the infrastructure and services assessment (including the development of an integrated preparedness plan) found that the two communities have some similar and some distinct vulnerable conditions with respect to preparedness and planning. The following section briefly describes the vulnerability of some fundamental infrastructure sectors in the study areas.

School preparedness. The vulnerability results for the schools in both communities are similar. They both have developed tsunami and disaster education curricula. School building standards are high with strong structural integrity. These structures can also serve as community shelters, stocked with food reserves and access to services in case of emergency.

Water supply services. The two study communities depend on different sources of water. Namkhem gets their water from the PWA (Provincial Waterworks Authority) whereas Kamala gets their water from the TAO (Tambon or Sub-district Authority Organization). We found that water quality and capacity measures are incomparable. Fortunately, due to higher average income levels in Kamala and to the fact that the TAO is located outside of the flood zone, water quality and services have the potential to be easily improved.

Road networks/evacuation routes. In Namkhem, there are good planning and preparedness activities in place that involve the local community. Although crowded in some areas, the spatial plan of the community includes an agreement with the villagers that divides people into evacuation routes in order to mitigate traffic jams during evacuation. Namkhem does face problems associated with hazardous evacuation routes and shelter locations. In contrast, Kamala's evacuation routes are in better shape and can efficiently accommodate high capacities of people. An important concern in Kamala is that people do not tend to follow preparedness patterns and planned evacuations, and villagers prefer to find their own evacuation routes.

FIGURE 5
Vulnerability map of Namkhem and Kamala



Data from the building vulnerability (BV) assessments were analyzed using weighting factors that describe the significant features related to the vulnerability of buildings. These factors include building materials and design, sea defenses in front of buildings, surrounding roads, building height, and characteristics of ground floor design. The individual building vulnerability assessment results (Papathoma and Dominey-Howes 2003) are as follows:

Namkhem. The majority of residential buildings in Namkhem are situated along the waterfront. Because the daily lives of residents revolve around fishing the easily accessible shore and pier make living near the water attractive. Since this study was focused on assessing vulnerable areas, all of the buildings we studied are located in high inundation zones (see Figure 5). 45 buildings out of 94 (or 47.87%) registered high BV values.

Kamala. A number of buildings constructed both before and after the 2004 tsunami 2004 are located along shoreline. This is a response to the needs of the tourist based economy. In Kamala, 29 buildings out of 113 (25.66%) had high BV values. This was less than recorded medium and low BVs. The low BV category contains new buildings built for tourism (i.e. hotels and guesthouses) which have adhered to building codes and regulations.

6.2.2 Comparative Assessment Results

The results of the assessment show that buildings, road networks, and evacuation routes represent significant vulnerability points in both communities. Some comparative differences and influencing factors include the following:

Buildings. A large proportion of buildings in Namkhem were categorized as having high BV. Most of the buildings are single story units with low standards of construction. Comparatively, Kamala has a much lower number of high BV buildings. Most of the building stock is made up of commercial buildings including hotels and guest houses. Namkhem is made up of mostly low-income families who lack the financial resources to improve their homes. In contrast, Kamala is a higher income community, economically buoyed by tourism. Here, the majority of buildings are made up of high quality materials and are built to high standards of structural design/construction.

Road networks/evacuation routes. In Namkhem, there is high utilization of road networks and construction materials, and high numbers of users in the event of an emergency (specifically in the Lam Son area). The road network vulnerability (RV) assessment (based on multi-criteria method involving route location, embankment height, design and construction standards, number of users and functional importance) reflects different vulnerability levels across Namhem and Kamala. 50% of roads in Namkhem have high RV whereas only 20% have high RV in Kamala (see Table 5). The key vulnerability factors are a lack of resources for the development of efficient evacuation routes and poor community land-use planning.

TABLE 5
Road Network Vulnerability (RV) Assessment Results

Namkhem	**High Inundation Zone**	**Medium Inundation Zone**	**Low Inundation Zone**	**Total RV**
High RV	16.67%	33.33%	0	50.00%
Medium RV	0	16.67%	16.67%	33.33%
Low RV	0	16.67%	0	16.67%
Total	16.67%	66.67%	16.67%	100.00%
Kamala	**High Inundation Zone**	**Medium Inundation Zone**	**Low Inundation Zone**	**Total RV**
High RV	20.00%	0	0	20.00%
Medium RV	0	20.00%	0	20.00%
Low RV	0	40.00%	20.00%	60.00%
Total	20.00%	60.00%	20.00%	100.00%

Source: Calculated from results of field survey (in December 2008)

6.2.3 Current Adaptation Strategies

Based on the vulnerability assessment results, major influencing factors can be identified and used as part of identifying required adaptation strategies in order to enhance the resilience. Data collected from our interviews and focus group discussions, principles of vulnerability reduction, and existing strategies and adaptation measures are identified in Table 6.

TABLE 6
Existing Strategies in the Study Areas

Community Adaptation	Namkhem	Kamala
Institutional framework	• Integrate disaster plan into sustainable eco-tourism plan	• Adapt some measures such as land use zoning, and building control
Access to training and education	• Develop disaster management curriculum in Namkhem school • Provide training program for vulnerable groups	• Develop the curriculum for school children • Provide training by Kamala TAO for Disaster Relief Volunteer members
Public awareness enhancement	• Develop disaster practice program for community members	• Develop preparedness program involving community members
Access to technology	• Use of radio communication system in Disaster Relief Volunteers Foundation • Apply community radio broadcast for daily news and special activities	• Use of radio communication system in Kamala school • Use of mobile-speaker on vehicles by TAO
Infrastructure adaptation	• Attempt to change sea beach to be public park, although the actual condition seems to be not working	• Develop structural landscape involving architects and engineers during the planning, design and construction phases

Source: Interviews and focus group discussions (in December 2008)

6.2.4 Proposed Adaptation Strategies

Based on our case studies, we've developed the following recommendations for appropriate, resilience enhancing adaptation strategies:

Strengthening/implementing regulations. In the context of land-use control for hazard mitigation it is fundamental for the authorities to ensure that all structures are consistent with established disaster and environmental policy regulations.
Formulation of coastal zone management plans. Due to the coastal zone hazard risks, understanding potential impacts is critical to effective coastal zone management. Strategic coastal zone management plans can significantly reduce the detrimental impacts of climate change. This strategy can be adopted by communities where coastal environmental resources have been degraded, in order to avoid unwanted impacts (i.e. landslides, floods, and other hazards).

Public awareness and education. Strong public knowledge and understanding of local hazard risks and vulnerability is important for increasing coping capacity and initiating successful mitigation and/or adaptation measures. Public participation in community preparedness programs is essential. Education initiatives should become a priority for decreasing social vulnerability because knowledge ultimately leads to reductions in physical vulnerability.

Provision of practical incentives. Incentives such as government grants and subsidies may help villagers improve their buildings and/or reconstruction projects. Insurance can also provide useful incentives for vulnerability reduction. For example, insurance companies may be persuaded to offer reduced premiums for residential buildings in Kamala. Similarly, it might also be a useful strategy in Namkhem for governments to provide incentives/financial support for building construction.

6.3 Findings

The two case studies illustrate different levels of hazard vulnerability related to coastal housing and infrastructure services. Major factors influencing community vulnerability are the community's economic base, financing ability for improved construction, support from local governments and community-based organizations, and levels of accessibility to knowledge about improved disaster management. Based on the vulnerability results and required capacity, four types of strategies for adaptation and mitigation are recommended: strengthening/implementing regulations, formulation of coastal zone management plans, public awareness and education campaigns, and provision of practical incentives.

7. CONCLUSION AND RECOMMENDATIONS

In many ways the impacts of climate change are unavoidable up to certain extent. There is, however, a need to consider adaptation strategies in order to adjust to climate change related risks. Mitigation strategies can also reduce the adverse impacts of climate change. This study takes into account the vulnerability assessment process and adaptation process for enhanced resilience in understanding the physical, societal and environmental vulnerabilities subject to climate variability, and assessing the adaptation strategies to possibly support policy makers in integrative decision making process. The resilience capacity and strategies should be based on the local vulnerability assessment. The cases included in this study show that the flood risk has several consequences in different urbanization levels and under the climate variability. Major factors influencing vulnerabilities of selected coastal communities are related to economic aspects, institutional capacity, and level of and accessibility to knowledge in local community-based organizations. Based on the vulnerability results and required capacity, we were able to identify and propose specific types of strategies for adaptation and mitigation under the coastal hazard conditions of the communities.

This study will help support policy makers in integrative decision making processes which may be used in different sectors - especially in disaster/risk management plans, water resource management, health, sustainable livelihoods, institutional structures, project design and implementation, etc. The assessment process developed in this study can be augmented by employing additional assessment methods such as multiple vulnerability assessments and benefit-cost-effectiveness tools. Some of recommended areas of future research include: study in different urbanization levels with potential hazards at different projections of climate change; integrated assessment for relationships of regional climate changes impacts and specific local risks; and increasing community resilience to disaster/climate risk through the use of available good practices.

Acknowledgements

The authors would like to acknowledge the support, leading to this paper, of the following: Franco-Thai Cooperation Program under Thai Commission on Higher Education, Canadian International Development Agency, Netherlands Ministry for Development Cooperation, Royal Thai Government, and School of Environment, Resources and Development (Asian Institute of Technology). The appreciation also goes to a number of national and local agencies and personnel related to the four study communities for generous support in data collection.

References

Asian Development Bank. 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review.* Mandaluyong City, Philippines.

Asian Disaster Preparedness Center. 2003. *Disaster Management in Southeast Asia – An Overview.* Bangkok, Thailand.

Cruz, R. V., Harasawa H., Lal M., Wu S., Anokhin Y., Punsalmaa B., Honda Y., Jafari M., Li C., and Huu Ninh N. 2007. "Asia." In *Climate change 2007: Impacts, Adaptation and vulnerability,* Parry, M. L. Pary, Canziani O. F., Palutikof J. P., van dser Linden P. J. and Hanson C. E., 469–506. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

CSIRO. 2006. *Climate change in the Asia/Pacific region.* VIC, Australia.

Dasgupta, S., Laplante B., Meisner C., Wheeler D., and Yarn J. D. 2007. "The Impacts of Sea Level Rise on Developing Countries: A Comparative Analysis." Policy Research Working Paper 4136, World Bank, Washington, D.C.

Dick, H., and Rimmer P. J. 2003. *Cities, Transport and communications – the Integration of Southeast Asia since 1850.* New York: Palgrave Macmillan.

Dolan, A. H., and Walker I. J. 2003. "Understanding Vulnerability of Coastal Communities to Climate Change related Risks." *J. of Coastal Research* Special Issue 39.

Hardoy, J. E., Mitlin D., and Satterthwaite D. 2001. *Environmental Problems In an Urbanizing World – Findings Solutions for Cities in Africa, Asia and Latin America.* London: Earthscan.

IPCC (Intergovernmental Panel on Climate Change). 2007. "Summary for Policymakers." In *Climate change 2007: Impacts, Adaptation and vulnerability,* Parry, M. L. Pary, Canziani O. F., Palutikof J. P., van dser Linden P. J. and Hanson C. E., 7–22. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

ISDR (International Strategy for Disaster Reduction). 2005. "National Report on Disaster Reduction in Vietnam." Paper prepared for the World Conference "Disaster Reduction," Socialist Republic of Vietnam.

Julius, S. H., and Scheraga J. D. 1999. *The TEAM Model for Evaluating Alternative Adaptation Strategies.* Global Change Research Program, Office of Research and Development.

Kay, R. C., and Hay J. E. 1993. "Possible Future Directions for Integrated Coastal Zone Management in the Eastern Hemisphere." Discussion Paper. In *Proc. Eastern Hemisphere Workshop on Vulnerability Assessment of Sea Level Rise and Coastal Zone Management*, ed. Minura, N. and McLean R., 181–94. International Panel on Climate Change Regional Workshop, Tsukuba, Japan.

New Zealand Ministry for the Environment. 2008. *Coastal Hazards and Climate Change — A Guidance Manual for Local Government in New Zealand,* 2nd Ed., Wellington, New Zealand.

Papathoma, M., and Dominey-Howes D. 2003. "Tsunami Vulnerability Assessment and its Implications for Coastal Hazard Analysis and Disaster Management Planning, Gulf of Corinth, Greece." *Natural Hazards and Earth System Sciences* 3: 733–47.

Rattanapan, A. 2009. Disaster *Vulnerability Assessment for Housing and Infrastructure of Coastal Communities in Southern Thailand.* Master Thesis, Asian Institute of Technology, Thailand.

Sacarufi, P. 2008. "The World Natural Disasters Ever." http://www.scaruffi.com/politics/disaster.html. [Accessed April 16, 2009].

Socialist Republic of Vietnam. 2005. "National Report on Disaster Reduction in Vietnam." World Conference on Disaster Reduction, Kobe-Hyogo, Japan.

Tu, T. T. 2009. *Adaptation to Flood Risk in Coastal Urban Area under Rapid Urbanization and Climate Change in Ho Chi Minh City, Vietnam*. Master Thesis, Asian Institute of Technology, Thailand.

UN (United Nations). 2001. *World Urbanization Prospects: The 1999 Revision.* New York.

UNEP (United Nations Environment Program). 2005a. *Tsunami Thailand: One Year Later - National Response and International Partner.* United Nations Country Team in Thailand, Bangkok.

______. 2005b. *National Rapid Environmental Assessment - After Tsunami Rapid Environmental Assessment*, Bangkok.

UNESCAP (United Nations Economic and Social Commission for Asia and the Pacific). 2008. *Statistical Yearbook for Asia and the Pacific 2008 - Natural Disasters,* 207–13. Thailand.

World Bank. 2007. *East Asia Environment Monitor 2007 — Adapting to Climate Change.* Washington, DC: World Bank.

CHAPTER 30

Built-In Resilience: Learning from Grassroots Coping Strategies to Climate Variability

Huraera Jabeen, Adriana Allen, Cassidy Johnson*

1. INTRODUCTION

It is now widely acknowledged that the effects of climate change will disproportionately increase the vulnerability of the urban poor in comparison to other groups of urban dwellers (Alam and Golam Rabani 2007; McGranahan, Balk and Anderson 2007; Pelling 2003; Satterthwaite et al. 2007). While significant attention has been given to exploring and unpacking 'traditional' coping strategies for climate change in the rural context – with a focus on agricultural responses and livelihoods diversification, with few exceptions, there is less work on understanding the ways the urban poor are adapting to climate variability. The central argument of this paper is that significant lessons can be drawn from examining how the urban poor are already coping with conditions of increased vulnerability, including how they respond to existing environmental hazards such as floods, heavy rains, landslides, heat and drought. Knowledge of these existing coping capacities for disaster risk reduction can help to strengthen planning strategies for adaptation to climate change in cities because they draw on existing grassroots governance mechanisms and support the knowledge systems of the urban poor.

The purpose of this paper is to examine the coping mechanisms developed and adopted by the urban poor and to discuss how these mechanisms can be mainstreamed into urban planning responses to climate change adaptation. The research focuses on local coping strategies that can be observed in the built

*Corresponding author: cassidy.johnson@ucl.ac.uk

environment such as how people adapt their houses, living spaces, streets, open spaces and infrastructure to cope with existing environmental hazards.

Conceptually and methodologically, the research comes from the disaster management perspective, drawing on a background of vulnerability and resilience literature and published case studies about coping mechanisms in urban areas and/or coping mechanisms for the built environment. The paper draws on primary data collected by the authors in Korail area, the largest informal settlement in Dhaka, Bangladesh. The origin of Korail dates back to the 1980s, and it is located in the low-lying flood-prone area of the city. It provides fruitful ground to explore the existing 'built-in' resilience of a poor urban settlement which would normally be considered extremely vulnerable and at risk.

The paper is organized in three sections. The following section sets the background by establishing the relations between adaptation, disaster risk reduction and coping strategies for urban areas. The next section summarizes the existing coping strategies of the urban poor in Korail, using the findings of the survey data. It highlights how the urban poor effectively use physical, economic and social means of gaining access to safety, reduce their loss and facilitate their recovery. The third section discusses how local planning and governance mechanisms aimed at adaptation can support these existing coping strategies and provide recommendations to mainstream them into adaptation plans that can be scaled up at the city wide level.

2. LOCAL COPING MECHANISMS FOR ADAPTATION AND DISASTER RISK REDUCTION

2.1 Making the Links Between Adaptation and Disaster Risk Reduction

The integration of disaster risk reduction and climate change adaptation is advancing as these two fields come closer together in understanding that reducing socio-economic vulnerability to hazards or effects from climate change, amount to similar schools of thought (Schipper and Pelling 2006; Tomalla et al. 2006). The two fields use subtly different language to describe similar activities. From the field of disasters, the term 'coping capacity', is concerned with the means by which 'people or organizations use available resources and abilities to face adverse consequences that could lead to a disaster' (UNISDR 2009). In the climate change field, the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment identifies coping ranges as "the capacity of systems to accommodate variations in climatic conditions" (Carter et al. 2007:142) and discusses how under the scenario of a changing climate, risks may increase but that adaptation actually expands a system's coping ranges. Following on this, the IPCC uses the term 'adaptive capacity' as the ability of a system to adjust to *climate change* (including *climate variability* and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (emphasis in the original) (Carter et al. 2007:869). Satterthwaite et al. (2007) relate this definition to the urban scale, thus describing 'adaptive capacity' as the "inherent capacity of a system (e.g. a city government), population (e.g. low-income community in a city) or individual/household to undertake actions that can help avoid loss and speed recovery from any impact of climate change" (p.5) Thus, both 'coping capacity' (disasters) and 'adaptive capacity' (climate change) are determined by a community's or a system's abilities to take actions that will help them to withstand hazardous events.

2.2 Urban Coping Strategies

Coping strategies are often complex. However, the assumption is that an event will follow a familiar pattern, and that actions that were taken before to cope are a reasonable guide for similar events (Wisner et al. 2004). Coping strategies can generally be:

- *Preventive strategies* — at the individual and small group level, these mean people making choices so that they will not be affected by an event, such as avoiding dangerous places at certain times or choosing safe residential locations.
- *Impact-minimizing strategies* — These are strategies to minimize loss and to facilitate recovery in the event of a loss. This is generally referred to as 'mitigation' in disaster literature, but 'adaptation' in climate change literature. Very simply, this should imply improving access to a minimum level of food, shelter and physical security so that people will be less vulnerable in case a disaster or climatic event does happen.

Coping strategies operate within different scales: individual (e.g. household), community (e.g. neighbourhood) or institutional (e.g. city-wide or beyond). Individual coping strategies, which operate at the level of the household unit entails cooperation on activities within the household, but not beyond. Coping strategies operate at the community level when members of a community work together to improve their resilience. This requires a certain level of organisation beyond the household and may involve community-based organisations, religious organisations or other organisations that operate as an organising entity within the community. Local governments or NGOs may operate institutional level coping strategies, however, the urban poor generally have little power over these — rather their sphere of influence is at the individual or community level. Wisner et al. (2004) and Wamsler (2007) identify several different types of coping strategies, some of which correspond to strategies that the urban poor use:

- *Building up stores of food and saleable assets:* storing of food may be more common in rural areas, but urbanites living in a cash-based economy may use similar strategies such as keeping items of value that can be sold if needed.
- *Diversifying income sources*: In cities this may mean illegal or quasi-legal work, such as street-hawking, waste recycling, or even looting and pilfering in areas that have been affected by a disaster. Having more than one, or sometimes several, income earners in the family also allows for diversification. If families have contributed to savings groups, this can offer a form of income during hard times.
- *Development of social support networks*: This is the ability to call on the resources of others during difficult times. Networks can be within the household, between extended family members (living near or afar), within neighbourhoods, and with wider groups who have a shared identity (religious, geographic, commercial, etc.). Assistance can come in many forms – financial help, emotional support, shelter in time of need, or physical helping of any kind. These types of networks maybe less present in urban settings due to the erosion of traditional systems that govern social interactions. Also, transience is quite common in urban settings, so families may not have the opportunity to establish these important networks.

2.3 Grassroots Coping Strategies for the Urban Built Environment

As detailed above, coping strategies can entail many different kinds of activities, including the use of social networks, diversification of income sources or collective savings. Many important coping strategies employed in cities consist of modifications to the physical and built environment. Wamsler (2007) refers to physical/technological risk reduction as 'the structural and non-structural improvements of dwellings and surroundings.' She also refers to environmental risk reduction, which is the use and removal of natural resources, including clean-up of the natural environment. Studies of coping strategies for the physical and built environment highlight several common features of urban populations under risk (Nchito 2007; Satterthwaite et al. 2007):

- *The poor usually inhabit informal settlements in the most hazardous locations in the city, and thus are most at risk when a disaster or climatic event happens*. The poor often build on leftover land on floodplains alongside the river, or on unstable hills surrounding the city susceptible to landslides. They may live close to garbage dumps or toxic industries or end up inhabiting the areas most prone to strong ground motion in earthquakes. Informal settlements often lack basic infrastructure of paved roads or adequate drainage and thus are more susceptible to flooding. Lack of open spaces and little green areas mean that informal settlements may suffer from higher temperatures.

- *Informal developments often aggravate flooding and heat*. Flooding frequency, magnitude and duration can become stronger, as informal developments on floodplains restrict water runoff. Lack of open spaces and clearance of natural vegetation create stronger urban heat island effects.
- *Relocation is not an option* that the urban poor will agree to take in times of a disaster or a climatic event, unless they absolutely must. People do not feel safe leaving behind their belongings and often cannot afford to be far away from income earning possibilities.

Coping strategies for the physical and built environment operate at different scales. The following activities are common (Wamsler 2007; UNFCCC 2004; Douglas et al. 2008):

- *Within the house*: raising furniture in the house, building furniture that is higher so that people can rest on it during the flood, blocking entryways so that water cannot come in, creating outlets so water can flow out easily, turning off electricity;
- *Modifications to the house structure*: installing rain gutters, replacing walls or supporting structures with flood-resistant materials, i.e. bricks or cement, using light coloured materials to reflect heat, using lateral reinforcing with wood or bamboo for earthquakes and hurricanes, nailing down roof materials.
- *Modifications around the house:* digging water channels, building dykes, laying sandbags.
- *Improvements at the neighborhood level*: cleaning drains that service several houses, building retaining walls, putting plastic sheets on slopes.

Cooperation beyond the household—at the community or institutional level—is usually necessary for the neighborhood level coping strategies. Investments in roads and pathways, drainage and sanitation systems, and improvements to open spaces can reduce the frequency and magnitude of disaster events but require collective action. Some of the most effective adaptation strategies may be beyond the control of the local community and must be implemented at the institutional level. For example, tenure systems that allow the urban poor security of tenure mean that people will invest in improvements to their houses.

As part of any adaptation plan, outside agencies must understand existing local coping strategies and build upon them (Huq and Ried 2007). Davis (2004) outlines the need to build a detailed understanding of the scale and nature of the coping strategies of communities at risk and makes the point that these coping strategies need to be integral to disaster plans. Moser and Satterthwaite (2008) highlight the need to support initiatives that build resilience at household and community levels.

3. CASE STUDY: KORAIL, DHAKA

3.1 Vulnerability of Dhaka

Bangladesh in general is vulnerable to climate variability and climate change because of its geomorphologic location. The capital city Dhaka has experienced nine major floods in the last 55 years among which those of 1988, 1998 and 2004 were severe due to overflowing of surrounding rivers. Flooding from excessive rainfall also causes severe problems in certain parts of the city, which are inundated for several days mainly due to drainage congestion and inadequate pumping facilities. In addition, the city experiences 'heat island' problems where the temperature is a few degrees higher than the surrounding areas. These affect infrastructure including water systems, housing and settlements, transport networks, utilities and industry. The 3.4 million urban poor living in Dhaka with limited or no access to services and poor living conditions are considered highly vulnerable among all the city dwellers (CUS 2005). In addition to physical impacts, vulnerability increases through insecure livelihoods, increased health risks and constrained economic activities.

3.2 General Description of Korail

The informal settlement in Korail, considered the biggest slum in Dhaka, started to develop during late 1980s on the vacant higher grounds. Eventually the settlement expanded, encroaching the highly vulnerable water edges. At present, Korail covers an area of approximate 90 acres with an estimated population of over 100,000 (CUS 2005). The eastern and southern edges of the area are defined by the Gulshan Lake, a main water reservoir for the adjoining areas. Because of its location near the high-end residential and commercial areas (Gulshan, Banani and Mohakhali) of Dhaka, it attracted low-income people engaged mostly in service jobs, like cleaners, household helpers, rickshaw pullers as well as workers in the ready-made garments industries.

The people of Korail experience climatic hazards almost every year from excessive rainfall, increased heat and flooding.High population density without proper services and locations at the vulnerable water's edge impose threats from climate variability and climate change. Security of tenure is one of the major concerns for the area. Since two government organizations own most of the land, ownership of land acts as a threat of eviction. This insecurity has caused reluctance among service providing authorities to give legal access to city-wide systems, therefore local dwellers are forced to pay higher prices for water and electricity to illegal providers. Lack of tenure security also has the consequence that the inhabitants, including those who have lived there for as long as 20 years, are unwilling to invest in improving their living conditions. High density self-help housing in the area was developed without any government intervention. Different NGOs worked in the area to develop segmented drainage, sanitation, garbage disposal as well as informal education and healthcare facilities.

3.3 Methods

A small qualitative survey was conducted among 35 households to identify their experiences of climatic variability, hazards and coping strategies. The households have been chosen randomly based on the criteria of location, condition of houses, ownership and period of tenancy. Among the 30 households finally documented, 14 lived near the water's edge highly susceptible to flooding, while the other 16 lived on higher ground in high density areas with or without drainage facilities. The housing condition varied from permanent to temporary in character and the period of tenancy varied from less than one year to more than five years. The survey included interviews with at least two household members (male/female) preferably at two different times. The survey questions were designed in consultation with local inhabitants and academics with options of flexibility and additions by the respondents. The answers of the respondents were compiled and analyzed using Microsoft Office Access, Excel and SPSS. Notes, pictures and sketches provided an important basis for the documentation.

3.4 Findings

3.4.1 Population

The 30 households comprised a total of 163 members; 36% of the survey population are within the age group of 15 to 30 working as principal earning members, employed either as service providers or self-employed related to services. Any climatic hazards would reduce their earnings from fewer hours and days worked. 17% of those aged between 35 and 45 earned from either renting out rooms or running household-based small businesses. Renting out rooms becomes problematic during rainy seasons because of water logging and flooding. The population pyramid of the survey population shows almost 30% under the age of 10 years. This raises two major concerns for the future: high dependency on the working household members will increase the vulnerability of the children as well as their susceptibility to long-term impacts of disaster resulting from climate variability and climate change. Also there is a high rate of illiteracy and low level of formal education, limiting access to information and increasing vulnerability.

3.4.2 Economic Abilities

There is a wide variation among the earnings of individuals as well as among combined households. Although 19 of the 30 households show individual earnings of less than 1 USD (BDT 70) per day, 40% of the households have combined earnings in the range of BDT 5000-9000, indicating availability of livelihood opportunities. Some 20% of households have incomes of more than BDT 17,000 per month, which is quite high in comparison to other informal settlements in Dhaka. 36% of individuals earn up to BDT 3,000 per month. Average working hours of the working individuals are 10.5 hours and 26 days per month. But there is a very high economic dependency rate of 59.5% on the working members.

3.4.3 Tenancy and Migration

Most of the households migrated to this area from other parts of the city because of the availability of vacant land, familiarity with the area and proximity to livelihood opportunities with an aspiration to move into comparatively permanent locations. 90% of households have had some experience of eviction in the past. The principal reasons for those migrating from villages were aspirations for a better life and to move with the family. Approximately 7% of households identified river erosion and loss of livelihoods as one of the reasons for migration from the village. Most of the households moved near to their extended family or people from the same village or region.

3.4.4 Experience of Disaster and Climate Change Impacts

The facts of climate change are not evident for the inhabitants of Korail; Rather they recognize existing climate variability. They suffer from water logging and flooding during the regular monsoons as well as from untimely rainfall. Also, most of the older respondents felt there has been a reduction in the amount of rainfall since their childhoods. Increased heat is a major indicator of climate change and climate variability for most of the respondents. Heat increases the occurrence of diseases from water shortages, such as typhoid and diarrhoea, putting pressure on household earnings.

3.5 Activities of People Before, During and After the Disaster

3.5.1 Physical Coping Strategies

As mentioned earlier from Wisner et al (2004), coping strategies for the urban poor can be preventive as well as impact minimizing. In Korail, choosing a safe location to avoid danger is not an option for most of the squatters, as the option of building new rooms are now only possible through encroachment of water edges susceptible to flooding. Some of the renters move to higher lands by buying possessions from the older inhabitants. In that sense most of the households take few preventive actions before any disaster. Most of the impact minimizing actions have become integral parts of their regular practice generated from past experiences. For instance, they construct barriers at the door front (53.3%), increase the furniture height (43.3%), build higher plinths (30%) and arrange higher storage facilities (30%). Only 5 of the 30 households reported changing to weather-resistant building materials before the rainy season and storage of food and water before predicted flooding. Some of the households took initiatives to work with NGOs in the area to construct drainage facilities connected to the lake.

The families living in higher grounds away from the water's edge would construct minimum five-inch barriers at the door to safeguard the rooms from water logging from regular rainfall where drainage facilities are unavailable. Many households increase the height of furniture at least six to nine inches (two or three bricks) depending on the location. In Korail most of the rooms are arranged in a courtyard- type pattern, adjoining rooms facing a narrow passage-like shaded courtyard (Figure 1. Typically one household would occupy a single room whereas better-off households would use two rooms. To reduce the heat in the rooms made out of corrugated iron sheets, creepers are grown in the courtyards to cover the roofs. Most households also use some form of false ceiling materials or canopy made of cloths. This is a popular practice in rural areas that has been applied in urban shelters.

Houses living near the water's edge are usually built on stilts. The platform for the floors is made higher considering the flood level. These stilt houses have better ventilation and experience reduced heat compared to the houses inland. The wooden planks in the floor are preferred as they face fewer problems from water logging after heavy rainfall. The stilts have the flexibility to increase in height depending on the water leve, every time they are rebuilt. The techniques used in the joints between partitions with roof and floor enhance ventilation as shown in Figures 2 and 3. The stilt houses also have the options of incremental expansion and repair following any disaster.

FIGURE 1
Typical House Arrangements

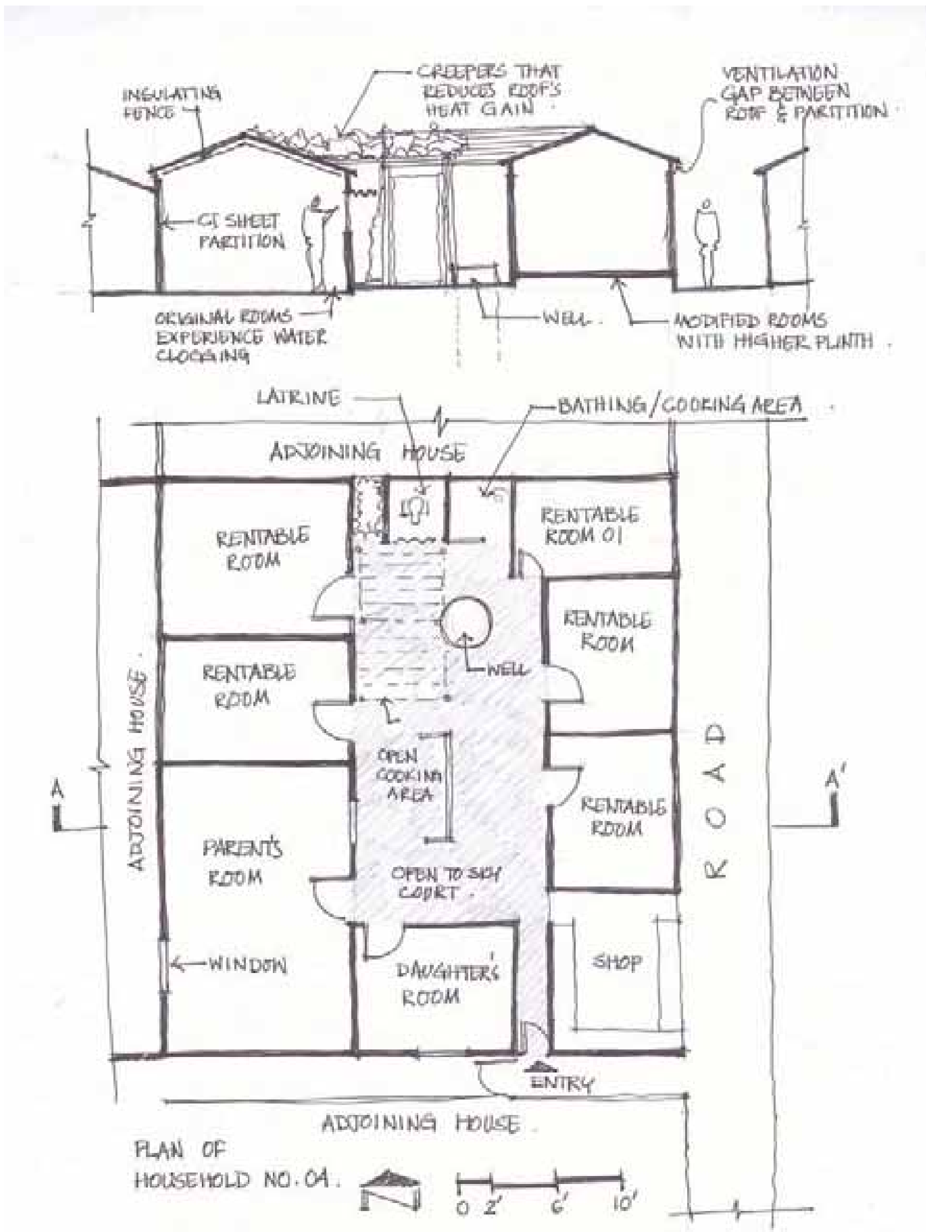


FIGURE 2
House 1 on Water's Edge

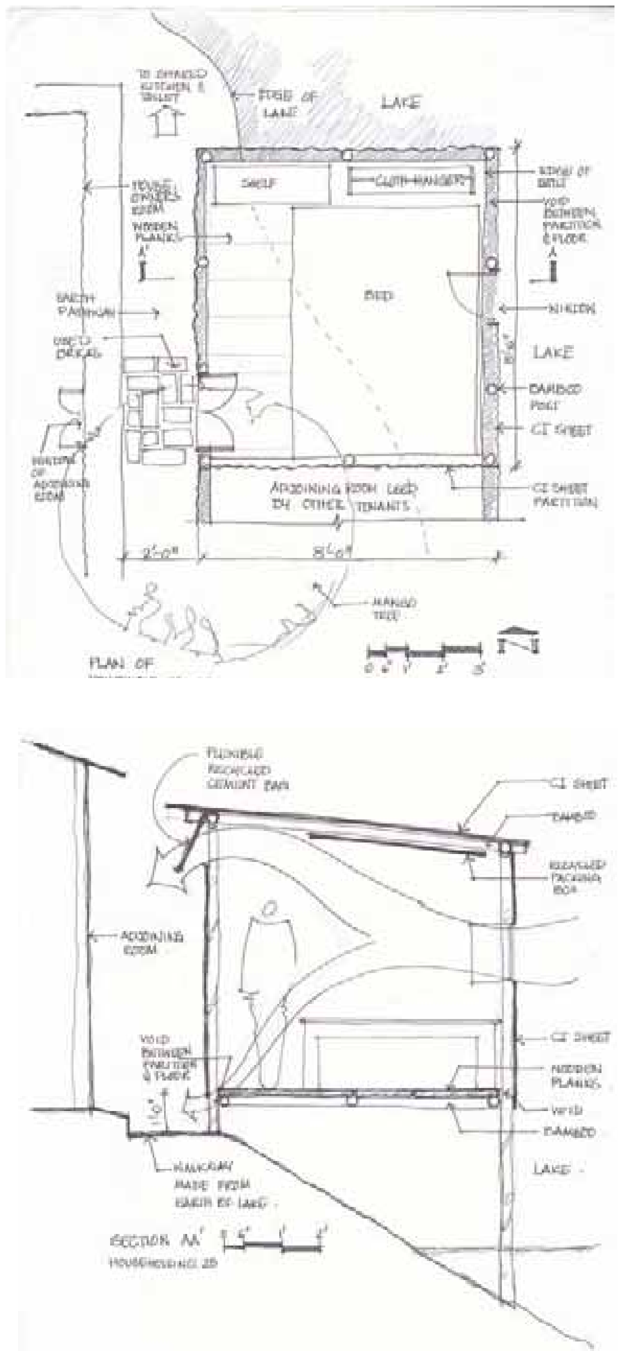
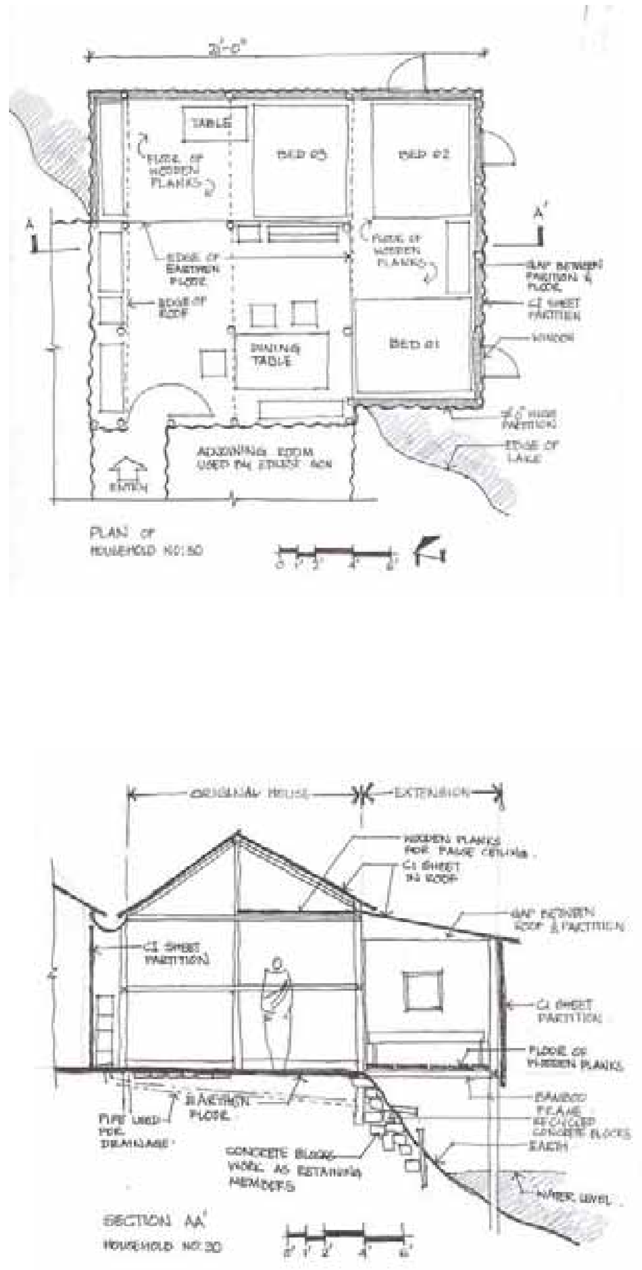


FIGURE 3
House 2 on Water's Edge



In Korail, during any disaster, moving to safer areas is not a preferred option as moving means losing assets, social and livelihood networks, and also possibly losing the right to live in the area. During flooding or water logging, the most practised option is to sleep on furniture above the flood level and use movable cookers for food preparation. Fourteen out of the 30 households shared services from unaffected neighbours. Some temporary measures were also taken, such as building higher barriers at the doors, making outlets at the house for easy flow of water, developing alternate means of access, building higher stilts inside the rooms, and community initiatives to clean drainage and move the most affected families to safer spaces within the neighborhood. 30% of the households suffered from food shortages during the previous flooding and prolonged water logging. Only 16% shared food with neighbours while 27% used money from their savings or borrowed from others.

To cope with the increased heat, most the households (70%) increase their power usage and buy additional electrical equipment during summer. Generally closely spaced structures create shaded courtyards that are used as open space for ventilation. Household activities are often held outdoors during frequent power shortages. The use of different insulating materials reduces the heat from corrugated iron sheet roofing and partitions. People use various kinds of recycled materials like paper, styrofoam, packing boxes, cement bags bamboo mats and old clothes for insulation.

After any disaster like flooding and water logging, 18 out of the 30 households rebuilt their structures in some way, from changing building materials, increasing plinth levels, changing materials for plinths to changing structural, roofing and walling materials. 30% of households took loans and got help from household members or neighbors for the purpose. There is a common practice among the households to save not only money but also building materials throughout the year for rebuilding after any future disaster. Fewer than 4% preferred to move to new locations after the last disaster as they are mostly renters.

3.5.2 Economic Strategies

Savings is seen as a main coping strategy for most of the households. 50% of households save regularly with savings groups or NGOs, with the intention to withdraw from their savings during and after any disaster. Usually savings groups are formed within extended families, neighborhoods and wider groups who have a shared geographical identity. They create a social and livelihood network through savings. The amount saved varies from BDT 200 to 2,800 per month, or about 3 to17% of total household income. Usually these households have more than one working member or income source from diversified occupations.

3.5.3 Social Networks and Safety Nets

The inhabitants of Korail have a very strong social network. This strong community base has prevented eviction in a number of instances. Typically, people migrating from a given area tend to settle near one another. 23 out of 30 households have some relatives or friends living in the city and 14 of them felt that they could seek assistance in the event of an emergency. Service sector employment in the private sector requires keeping professional and livelihood networks. More than 46% of households acknowledged having acquaintance with a professional group. Because of the courtyard living with shared services, there is a strong bond among different households. Households which rent out rooms also act as guardians for their tenants. People tend to be self sufficient, while sharing with neighbours.

Findings from areas like Korail raise concerns about the future of urban planning in the face of rapid urbanization in Bangladesh, on how to reorient and reduce effects of climate change and variability for the urban poor. As Dodman and Satterthwaite (2008) state, urban authorities can have a number of specific roles in reducing climate change vulnerability. They can introduce zoning and planning controls to help provide appropriate and safe locations for low-income households, while reducing exposure to the risks of flooding, slope failure and other disasters. The presence of a strong local government with capacity to develop a framework for future investments; land use management and the possibility to incorporate climate change adaptation measures is a prerequisite for such activities. However in Bangladesh, although few urban centres have such plans, in most case they are 'outdated, unenforced, or unenforceable'. The following section examines the possible contributions of local governments in mainstreaming adaptation plans.

4. SUPPORTING LOCAL COPING STRATEGIES THROUGH ADAPTATION PLANNING

4.1 How Local Planning and Governance Mechanisms Can Support Existing Coping Strategies

Local governments are better placed than any other government structure to deal with the effects of local climate events from a pro-poor perspective. However, adaptation to climate change is a relatively new issue for local government staff and this means that more often than not they engage with it through spontaneous responses triggered by urgent climate events usually interpreted as 'natural disasters'. In contrast with these spontaneous efforts, planned adaptation involves "a set of conscious policy and financial decisions made before signs of climate impacts become apparent or just after the first changes take place" (Deri and Alam 2008). Ideally, spontaneous and planned adaptation should be articulated to enable the local government to develop an integrated and systematic approach to climate change.

Whilst it is useful to bear in mind the distinction between 'spontaneous' and 'planned' adaptation, the former approach should not be underestimated or overlooked, as it constitutes the typical 'learning-by-doing' mechanism by which local governments can make good use of indigenous knowledge systems built up from the historical experience of urban dwellers and passed over from one generation to the next. These play a crucial role in contextualizing the adaptation process, generating community-wide ownership and commitment. Planned adaptation allows local governments to draw on scientific knowledge to map and predict climate risks.

There are a number of ways in which the two aforementioned approaches can be effectively articulated. The first step towards the development of robust local adaptation plans is for local governments to effectively engage in pro-poor adaptation to climate change in urban areas, promoting democratic and accountable local governance structures that actively challenge anti-poor attitudes among government bodies and engage key stakeholders from the private sector and civil society spheres to raise awareness, ensure the exchange and integration of various knowledge and skills, identify needs and priorities, evaluate scenarios and build collectively negotiated strategies. Local adaptation plans can be meaningless unless community organisations of the poor are systematically engaged and their short and long-term autonomous responses to climate change are understood, valued and supported.

The recent Bangladesh Climate Change Strategy and Action Plan 2008 reiterates the Government of Bangladesh's vision to eradicate poverty and achieve economic and social well-being for all, through a pro-poor approach prioritizing adaptation and disaster risk reduction. This focuses on six sectors, including comprehensive disaster management, infrastructure, research and knowledge management as well as capacity building and institutional strengthening. While this can be an opportunity for future activities, most of the detailed programs focus on rural areas. Apart from improving urban drainage under infrastructure development, the programs fail to address issues facing the urban poor such as food security, social protection, and disaster risk management.

A second area where local governments can play a crucial role in adaptation is by ensuring that land-use planning and the development of buildings and infrastructure take account of climate change risks. This poses several challenges as it requires planning and regulatory frameworks that not only prevent further developments in high-risk areas and support mitigation efforts, but also reduce the vulnerability of the urban poor and of collective infrastructure without imposing additional costs on the poor or obstructing their right to the city. Furthermore, infrastructure adaptation in the context of the developing world is compounded by the very large deficits suffered in urban areas and the poor quality and lack of maintenance of existing infrastructure. This implies that local adaptation to climate change cannot be divorced from a wider development perspective which focuses on tackling risk through lifeline infrastructure while planning to reduce disaster risk in future urban development.

The case of Korail vividly illustrates the reality of most informal settlements in the context of low and middle income countries, where a large percentage of the urban population lives, contributing more than their fair share to the development of socially, culturally and economically vibrant cities. Yet, their contributions are not only ignored but in many cases actively resisted, with local governments typically denying the provision of basic infrastructure and services to informal settlers and imposing additional threats through widespread forced evictions. Potential improvements by local dwellers to local infrastructure are often deterred by the insecurity of land tenure and the threat of eviction. The merits of securing land tenure in informal areas have been largely discussed elsewhere but cannot be emphasized enough. In the case of Korail, most of the land belongs to the state and there is therefore considerable room for a comprehensive land regularization programme.

Community-managed savings groups constitute a widespread mechanism employed by the urban poor and their federations to spread risk, increase their capacity to embark in affordable housing and the provision of infrastructure and services, and ultimately enhance their resilience to climate change-related risks (D'Cruz and Satterthwaite 2005). Local governments can support such savings schemes by backing their development into larger networks of savers — thereby helping to further spread their risks — and engaging in the co-production of housing, services and infrastructure, whilst ensuring that such developments are climate-risk sensitive. The savings patterns among the inhabitants of Korail exemplify such an opportunity.

Another area where local governments can play an active role is in the development of collective disaster risk transfer instruments to provide insurance coverage for low income groups. In the last decade, there has been increasing interest in the notion of risk transfer instruments (such as insurance), and their linkages with reconstruction and disaster mitigation programmes. However, there is still considerable room for development and innovation, particularly in relation to local/municipal approaches that effectively target the urban poor, who are typically unable to access the insurance market. The Bangladesh National Adaptation Programme of Action (NAPA) includes the consideration of micro-insurance for the poor using institutions involved in micro lending such as the Grameen Bank (Satterthwaite et al. 2007).

4.2 How Grassroots Coping Strategies Can Be Mainstreamed into Adaptation Plans and Scaled Up at the City-Wide Level

We started this paper by arguing that pro-poor adaptation to climate variability in cities demands a better understanding of the poor's adaptive capacity and of their autonomous coping strategies. This is because the urban poor are affected by the 'double vulnerability' of climate change and poverty, which means that they are disproportionately affected in terms of both their exposure to climate-related risks and the limited resources at their disposal to respond to such risks. Thus, support to local adaptation must pay attention to the differentiated impacts of and responses to climate change among different groups in society. However, there is a series of issues to take into account in order to mainstream this consideration into municipal adaptation plans in an effective and equitable way.

First, large uncertainties persist about the knowledge of observed short and long-term climate effects in urban areas, and in particular of how specific local conditions shape the vulnerability of the poor. Therefore, it is important to generate sustainable local means to identify and monitor climate change-related impacts and to integrate risk management principles and mechanisms of knowledge production and sharing into municipal adaptation policies and plans. In the process, the urban poor should be considered as both producers and consumers of such information and knowledge, addressing the striking gap in climate risk information by and for the urban poor.

Second, a fundamental problem rests in the fact that external support agencies are rarely set up to understand and support local governments and local community adaptation plans. There is thus a mismatch between the areas where increased local capacity and competence in climate adaptation is urgently needed, and the flow of development cooperation resources supporting adaptation. Bangladesh receives a significant volume of overseas development assistance (ODA) to support development activities, amounting to USD 1, 739 million during the 1998-2000 period. Out of this, it is estimated that the share of activities potentially affected by climate change risk — comprising climate-affected projects dealing with water supply and sanitation, renewable energy and hydropower, urban and rural development, food security and infectious diseases among other categories — has been as high as USD 500 million per year; whilst ODA committed to activities potentially affected by climate risk is considerably higher than that earmarked to support specific projects for climate change adaptation (Agrawala and Ahmed 2005).

The above discussion highlights that consideration of climate change-related risks could play a central role in financing both general development goals and adaptation responses, and reinforces the need to mainstream climate risk in the overall flows of development aid as a cross-cutting concern. However, this measure alone would not be enough for external funding flows to effectively support local adaptation plans. The problem requires a deep rethinking of the aid architecture to open a two-way direct dialog between international development agencies and urban authorities and dwellers, along the lines of decentralized cooperation programs and the creation of social funds for community adaptation.

Third, adaptation plans cannot be developed in isolation from other development strategies. Bangladesh's Poverty Reduction Strategy Paper (PRSP) gives limited consideration to the impact of climate change in planning vulnerability reduction strategies.

The lack of consideration of the specific impact that climate change will have on the urban poor both in the PRSP and international ODA is a product of the macro-perspective often adopted in addressing the links between development, poverty and increased vulnerability due to climate change effects. Thus, the task ahead is not only to incorporate the consideration of climate change impacts to urban programs and activities, but also a consideration of climate change vulnerability to any development intervention. Eriksen et al. (2007) argue that sustainable adaptation measures should be seen as those at the intersection of poverty reduction and vulnerability reduction measures.

Fourth, coping with climate change risks is not a new situation for the urban poor. Much can be learned from their slowly matured autonomous responses in order to build local adaptation policies and plans on the evidence-base of grassroots experience. Section 3 described the coping strategies developed by the poor in Korail, Dhaka. These range from physical adaptive practices in individual dwellings, through collective efforts to construct and maintain drainage facilities to the use of local social capital, for instance by sharing food and cooking facilities or moving to less affected building in the neighbourhood during flooding or water logging. About 50 percent of the households interviewed participate in savings schemes with the intention of drawing from their savings during times of hardship. Furthermore some strategies, such as the use of roof canopies or vegetation to reduce heat exposure, were identified as regular practices imported from the rural areas where many of Korail's current dwellers come from. The physical and social strategies adopted are mutually reinforcing, as shown in the wide use of courtyards also for outdoor inter-household activities that strengthen solidarity bonds among neighbors. As noted by Wisner et al. (2004) and discussed in section 2, grassroots coping strategies may comprise preventive or impact-minimizing actions, all aimed at reducing vulnerability through various mechanisms of technology use, social organization, economic relationships and cultural arrangements.

Fifth, city adaptation strategies require coordination across government agencies and utility providers and a combination of 'structural' and 'non-structural' approaches. The former term is often used in reference to "engineering interventions such as river channel modifications, embankments, reservoirs and barrages designed to control the flow of rivers and abate or control the spread of flooding" whilst non-structural approaches "typically refer to measures designed not to prevent floods but to reduce the short- and long-term impacts of the hazard….[including] formal flood warning systems and evacuation programs, land use controls on flood-prone sites, building regulations to prevent incursion of floodwaters and insurance schemes" (Few 2003:47). Over the time, the latter approaches began to pay more attention to community and household hazard coping strategies like the ones examined in this paper under Section 3.

At present a number of structural measures adopted by the Ministry of Environment and Forests, the Dhaka Water Supply and Sewage Authority and the Bangladesh Water Development Board are underway in Dhaka to improve environmental quality, manage floods and improve the drainage system. The severe destruction that took place in the 1989 floods prompted the adoption of the so-called 'crash programme', aimed at developing a comprehensive flood protection system both on the western and eastern parts of Dhaka. The first phase of the Dhaka Integrated Flood Protection Project in the western part of the city has been completed and effectively protected half of the city from complete inundation during the floods in 1998 and 2004. Non-structural measures include the banning of polythene bags which has allegedly reduced the regular clogging of the city's drainage system (Alam and Golam Rabbani 2007). Improvements to the city surface drainage system are still underway but progress has been delayed by the encroachment of many canals and canal banks by influential actors within local politics.

Last but not least, local adaptation plans cannot be promoted in isolation from effective mitigation responses. Although the national and local contribution to global greenhouse emissions is negligible, both are increasing. The energy sector in Bangladesh contributes more than 60 percent of the total annual greenhouse gases emitted in the country, and 25–30 percent of the emissions from the transport sector come from Dhaka city (Alam and Golam Rabbani 2007). Beyond a number of measures adopted by the local authorities to improve ambient air quality and reduce greenhouse gas emissions — such as the introduction of compressed natural gas in the transport sector — there is still plenty of room to reduce electricity consumption at household and industrial levels and to introduce changes in the transport sector.

5. CONCLUSION

Adaptive capacity and coping strategies can no longer be considered as different activities in policy and action in countries like Bangladesh. In the context of limited capacities of the government where actions should be taken to increase community and institutional capacities to withstand hazardous events, grassroots experiences, especially in the built environment, can form an effective knowledge base to plan for future.

Urban poor communities come together from their survival intuitions creating strong bonds at the individual and community levels. Preventive or impact-minimizing strategies may not be the best options to adapt to climate variability, but others like diversifying income sources or developing social support networks can eventually create pressures for change at the local government institutional level to make these an integral part of development plans. Local governments need to effectively articulate between 'spontaneous' and 'planned' adaptation. This can be done in different ways, from supporting saving schemes by backing their development into larger networks of savers, to ensuring that land use planning and development of buildings and infrastructure take account of climate change risks and address security of tenure issues. These require coordination across government agencies, utility providers and funding agencies, and a combination of 'structural' and 'non-structural' approaches.

Acknowledgements

A revised version of this paper has been published in the journal *Environment and Urbanization* for which the reference is: Jabeen, Huraera, Cassidy Johnson and Adriana Allen (2010). "Built-in Resilience: learning from grassroots coping strategies to climate variability." *Environment and Urbanization*, 22 (2): 415-431. This research was supported with funds from the British Council Bangladesh Higher Education Links Programme.

References

Agrawala, S., and Ahmed, A. U. 2005. *Bridge Over Troubled Waters: Linking Climate Change and Development*. Paris: OECD (Organisation for Economic Co-operation and Development) Publishing.

Alam, M., and Golam Rabbani M. D. 2007. "Vulnerabilities and Responses to Climate Change for Dhaka." *Environment and Urbanization* 19 (1): 81–97.

Allen, A., Hofmann P., and Griffiths H. 2007. "Report on Rural - Urban Linkages for Poverty Reduction." In *State of the World's Cities Report 2008: Creating Harmonious Cities,* United Nations Human Settlements Program (UN-Habitat). London: Earthscan.

Carter, T.R., R.N. Jones X. Lu, S. Bhadwal, C. Conde, L.O. Mearns, B.C. O'Neill, M.D.A. Rounsevell and M.B. Zurek. 2007. New Assessment Methods and the Characterisation of Future Conditions. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, 133–71. Cambridge, UK: Cambridge University Press.

CUS et al. 2005 *Slums of Urban Bangladesh: Mapping and Census*, CUS, Dhaka.

D'Cruz, C., and Satterthwaite D. 2005. "Building Holes, Changing Official Approaches: The Work of Urban Poor Federations and their Contributions to Meeting the Millennium Development Goals in Urban Areas." Poverty Reduction in Urban Areas Series, Working paper 16, IIED, London.

Davis, I., 2004. "Progress in Analysis of Social Vulnerability and Capacity." In *Mapping vulnerability: disasters, development and people*, ed. Bankoff G., Freks G. and Hilhorst D., 128–44. London: Earthscan.

Deri, A., and Alam M. 2008. "Local Governments and Climate Change." Commonwealth Secretariat Discussion Paper, 2, October, London.

Dodman, D., and Satterthwaite D. 2008. "Institutional Capacity, Climate Change

Adaptation and the Urban Poor." *IDS (Institute of Development Studies) Bulletin* 39 (4).

Douglas, I. et al. 2007. "Unjust Waters: Climate Change, Flooding and the Urban Poor in Africa." *Environment and Urbanization* 20 (1): 187–205.

Eriksen, S.E.H., Klein R.J.T., Ulsrud K., Næss L.O. and O'Brien K. 2007. *Climate change adaptation and poverty reduction: key interactions and critical measures.* Report prepared for the Norwegian Agency for Development Cooperation (Norad). GECHS Report. http://www.norad.no/items/10502/38/5649817983/GECHS%20Report%202007-1.pdf. [Last accessed on March 9, 2009].

Few, R. 2003. "Flooding, Vulnerability and Coping Strategies: Local Responses to a Global Threat." *Progress in Development Studies* 3 (1): 43–58.

Huq, S. and Reid, H., 2007. "A Vital Approach to the Threat Climate Change Poses to the Poor: Community-Based Adaptation," IIED Briefing. International Institute for Environment and Development (IIED), London.

McGranahan, G., Balk D., and Anderson B. 2007. "The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones." *Environment and Urbanization,* 19 (1): 17–37.

Moser, C., and Satterthwaite D. 2008. "Towards Pro-Poor Adaptation to Climate Change in the Urban Centre of Low- and Middle-Income Countries." Human Settlements Discussion Paper Series: Climate Change and Cities 3, International Institute for Environment and Development (IIED), London.

Nchito, W. S. 2007. "Flood Risk in Unplanned Settlements in Lusaka." *Environment and Urbanization* 19 (2): 539–51.

Pelling, M. 2003. *The Vulnerability of Cities: Natural Disasters and Social Resilience*. London: Earthscan.

Satterthwaite, D., Huq S., Reid H., Pelling M., and Romero Lankao P. 2007. "Adapting to Climate Change in Urban Areas: The Possibilities and Constraints in Low- and Middle-Income Nations," Human Settlements Discussion Paper Series: Climate Change and Cities 1, International Institute for Environment and Development (IIED), London.

Schipper, L., and Pelling M. 2006. "Disaster Risk, Climate Change and International Development: Scope for, and Challenges to, Integration." *Disasters: The Journal of Disaster Studies, Policy and Management* 30 (1): 19–38.

Tomalla, F. et al. 2006. "Reducing Hazard Vulnerability: Towards a Common Approach between Disaster Risk Reduction and Climate Adaptation." *Disasters: The Journal of Disaster Studies, Policy and Management* 30 (1): 39–48.

UNFCCC (United Nations Framework Convention on Climate Change). 2004. Database on Local Coping Strategies. http://maindb.unfccc.int/public/adaptation. [Last accessed on 15 April 2009].

UN/ISDR (United Nations International Strategy for Disaster Risk Reduction). 2009. *Unisdr Terminology on Disaster Risk Reduction*. Geneva: UN/ISDR. http://www.unisdr.org/eng/terminology/terminology-2009-eng.htm. [Last accessed on 26 January 2009].

Wamsler, C. 2007. "Bridging the Gaps: Stakeholder-Based Strategies for Risk Reduction and Financing for the Urban Poor." *Environment and Urbanization* 19 (1): 115–42.

Warner, K., and Bouwer L. 2005. "Financing Weather and Climate Risks" Report from Workshop 3. In *2nd International Work Conference on Climate Change and Disaster Risk Reduction,* 17-25. 21-24 June. The Hague.

Wisner, B. et al. 2004. *At risk: Natural Hazards, People's Vulnerability and Disasters*. 2nd ed. London: Routledge.

CHAPTER 31

City Health System Preparedness to Changes in Dengue Fever Attributable To Climate Change: An Exploratory Case Study

Jostacio M. Lapitan,* Pauline Brocard, Rifat Atun, Chawalit Tantinimitkul

Summary

City health system preparedness to changes in dengue fever attributable to climate change was explored in this collaborative study by Imperial College London and WHO Kobe Centre. A new toolkit was developed and an exploratory case study in Bangkok, Thailand was undertaken in 2008. This study found that there is a clear lack of research in this area, as most research looked at impacts and not at responses and preparedness for effective response. There is also a clear need to develop and/or scale up national-capital city efforts to assess and address the implications of climate change for health systems. It recommends further case studies to validate the toolkit and generate guidelines on how to develop effective response plans.

*Corresponding author: lapitanj@wkc.who.int

1. INTRODUCTION

The year 2007 marked the first time in history that 50% or more of the world's population lives in urban settings. 2007 was also the year that the science on climate change became unequivocal: the Earth is warming, as verified by the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC). Projections for increasing health impacts from accelerating climate change coincide with continuing trends of rapid, unplanned urbanization, signaling significant threats to public health. Climate change and its health impacts on vulnerable populations in urban settings are burning issues for development workers and disaster risk managers alike.

There is a significant increase in human mortality and morbidity as a result of climate change (Campbell-Lendrum and Woodruff 2007; Ebi et al. 2006; Patz et al. 2005; WHO 2003). Extreme weather conditions, such as heat waves, floods, storms, fires, droughts are occurring as a result of climate change (Campbell-Lendrum and Woodruff 2007; Campbell-Lendrum 2006; Hajat 2006; IPCC 2007; Patz 2002; Patz 2005; Vorosmarty 2000; WHO 2003; WHO World Health Day 2008). Increasingly, changes in global and regional climate patterns are affecting the dynamics and location of infectious diseases such as malaria, dengue fever, encephalitis, cholera, amongst others (Campbell-Lendrum and Woodruff 2007; Campbell-Lendrum 1996; Ebi 2006; IPCC 2007; Lipp 2002; Patz 2002; Patz 2005; WHO 2003; WHO World Health Day 2008).

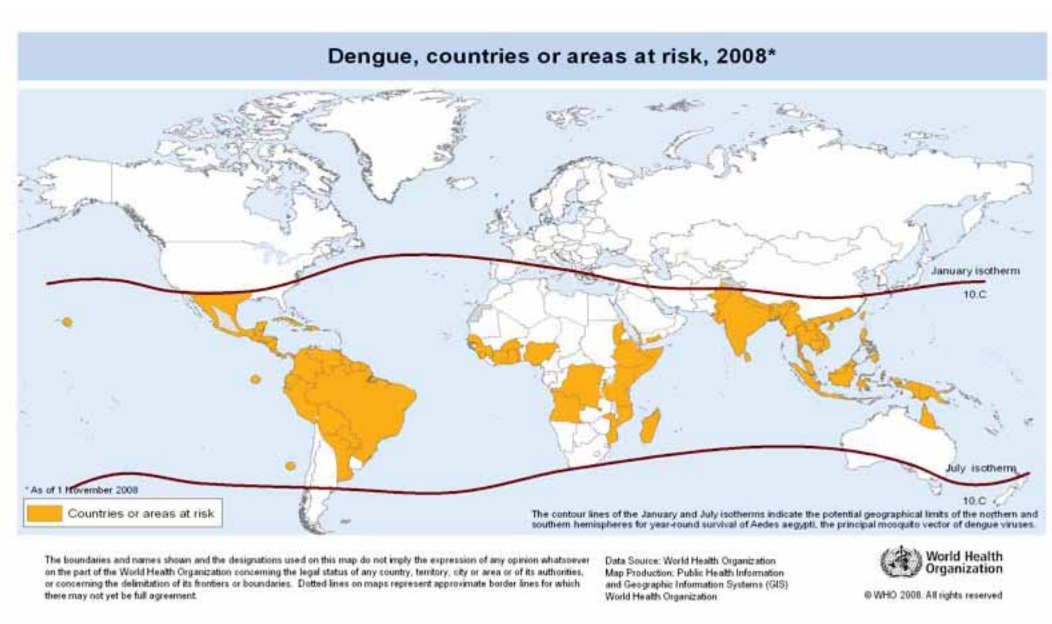
The main aim of this paper is to better understand the complexities associated with health system preparedness and planning in the context of changes in dengue fever epidemiology. The current body of research on dengue fever is concerned primarily with the upstream impacts of climate change and there is a clear lack of research on response. "Anticipatory prevention is better than reacting once a disease outbreak has occurred" (Bulto 2006). This systematic review of current response and preparedness to changes in dengue fever epidemics associated with climate change illustrates gaps in the literature and highlights the importance of this study. In this paper, we review previous research on increasing health plan preparedness for dengue fever, develop a toolkit to assess preparedness, and provide a case study of Bangkok, Thailand.

2. BACKGROUND & LITERATURE REVIEW

Dengue fever, also known as breakbone fever, causes a flu-like illness, and infects approximately 50 million people worldwide per year (WHO 2008). There are four serotypes of dengue fever. Patients who have had dengue have immunity for life from the serotype they have caught. However, patients who are infected with a second serotype are more likely to get dengue haemorrhagic fever (DHF) (WHO 2008). Dengue haemorrhagic fever is a more virulent form of dengue fever, and has potentially lethal complications (WHO 2008).

Dengue is a vector-borne disease, with its main vector being the *Aedes aegypti* mosquito. Dengue persists mostly in the tropical and subtropical regions of the world where the temperature and rainfall are adequate for the mosquitoes to thrive and breed (see Figure 1). It is an urban disease, with the vectors breeding mainly in water located in containers (Gubler, D.J., et al., 2001). Dengue fever is cyclical, with seasonal variations as well as bigger outbreak cycles every 2-3 years (WHO 2008, 2004a; Rodriguez-Tan and Weir 1998; Lifson 1996).

FIGURE 1
Worldwide Distribution of Dengue (WHO 2008)

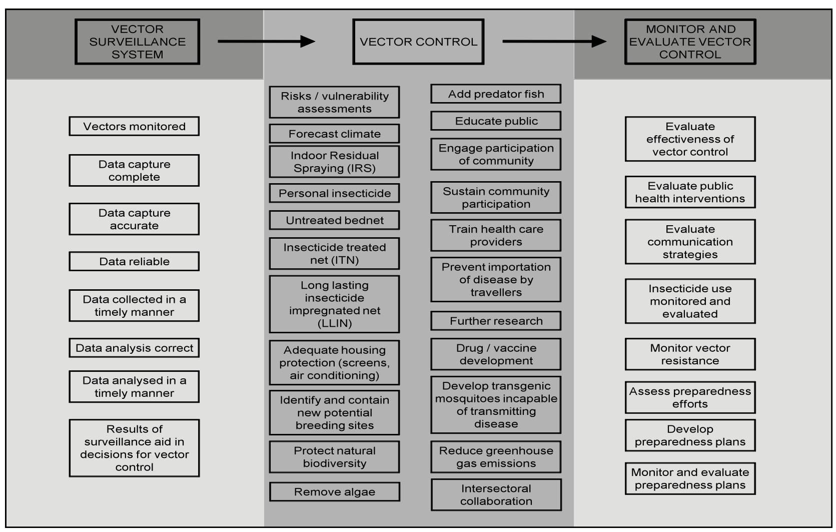


It is difficult to estimate the exact prevalence and incidence of dengue fever because only 30% of cases are symptomatic (Chen and Wilson 2005). The remaining 70% are either asymptomatic or produce only mild symptoms such as a low fever (Chen and Wilson 2005). Quick, commercially available diagnostic kits for dengue are relatively limited in developing countries. As a result doctors must treat patients for dengue fever symptoms without having a confirmed diagnosis. Incidence and prevalence of dengue hemorrhagic fever (DHF) is easier to estimate because all cases require hospitalization.

2.1 Dengue Control and Management

The potential control measures for dengue can be categorized by surveillance of the vector, control of the vector, and monitoring and evaluation of vector control (Figure 2), based on the WHO guidelines for dengue fever and DHF control (WHO 2003).

FIGURE 2
Vector Control for Dengue Fever



Climate change will lead to shifts in the prevalence and distribution of vector-borne diseases including dengue fever, and potentially has already caused some epidemiologic changes (Lifson 1996; Khasnis 2005; Gubler 2001; Sutherst 2004; Ye 2007). Dengue prevalence is likely to be affected by climate change due to the fact that the mosquito vector is cold-blooded and therefore more sensitive to changes in temperature, humidity and precipitation (Lifson 1996; Khasnis 2005; Lindsay 1996; Tanser 2003; Martens 1995; Hales 2002). The preponderance of the four flavivirus serotypes are associated with higher temperatures. The abundance and bite rate of *Aedes aegypti* mosquitoes, which transmit dengue fever by feeding during the day, are also affected by temperature, humidity and precipitation (Lifson 1996; Hales 2002; Hales 1999).

Describing the future of the environment and health process in Europe, the Fourth Ministerial Conference on Environment and Health stated "health aspects are still not well integrated into international and national initiatives, strategies, and action plans on sustainable development" (WHO 2004b) and that "A comprehensive strategy to support a public health response is conspicuously lacking" (Campbell-Lendrum and Woodruff 2007). This is a significant issue of concern and has been propelled forward by the agendas set in the recent WHO World Health Day 2008, report on climate change and health (WHO 2003a, 2008; Matthies 2008). Another catalyst for health preparedness was the publication of the 2008 World Bank guide, *How to climate-proof our cities* (World Bank 2008).

2.2. Literature Review

For the purpose of this paper, we conducted a systematic review of health system responses to changes in dengue fever as a result of climate change. The review follows the Cochrane criteria, with the goal of creating a clear, structured report, with repeatable results *(The Cochrane Collaboration)*. The review emphasizes the importance of context, and ultimately contributed to the development of the toolkit. The data sources used were EBSCO Business Source Complete with Business Searching Interface, Factiva, GreenFILE, Health Management Information Consortium International (HMIC) July 2008, JSTOR, Ovid Journals@Ovid Full Text June 09, 2008, and PubMed. To help ensure the quality of the data, only peer-reviewed publications were explored. A diversity of studies were included, such as randomized control trials and studies on response and preparedness to dengue fever.

The majority of the studies we reviewed explored the general health impacts associated with climate change and concentrated on vector-borne diseases. Only two of the reviews concentrated specifically on dengue fever, however they both only briefly mentioned climate change. Out of the four studies that collected data, three collected weather and climate data, two collected dengue data, two collected mosquito data, two collected socioeconomic data, and one collected response/adaptation data. Table 1 summarizes the characteristics of the studies included in the review.

Bulto et al. (2006), explored climate variability and *Aedes aegypti* and predicted "more frequent epidemic outbreaks and a change in the season and spatial pattern of dengue fever" in Cuba. In response to their results, the researchers suggested the use of climate projections to inform future policy decisions concerning the development of vector control programs.

Hales et al. (1999), investigated the relationship between the El Niño southern oscillation (ENSO) and dengue fever, and concluded that ENSO may trigger dengue fever outbreaks on large populated islands.

TABLE 1
Characteristics of Studies Included in Dengue Fever Review

Authors	Year	Specific Countries or Regions	Weather and climate data	Epidemiologic data	Ecologic data	Socio-economic data	Response / Adaptation data
Bulto et al.	2006	Cuba	Collected	None	Aedes aegypti collected	Collected	None
Campbell-Lendrum and Woodruff	2006		None	None	None	None	None
Frumkin et al.	2008		None	None	None	None	None
Gubler et al.	2001		None	None	None	None	None
Hales et al.	1999	South Pacific	Collected	Dengue fever cases	None	None	None
Lifson	1996	United States	None	None	None	None	None
Patz and Kovats	2002		None	None	None	None	None
Patz et al.	2000		None	None	None	None	None
Rawlins et al.	2007	Caribbean	None	None	Vector population and habitats	Collected	Community knowledge and willingness
Rodriguez-Tan and Weir	1998	United States	None	None	None	None	None
Sutherst	2004		None	None	None	None	None
Woodruff et al.	2006	Australia	Collected	Dengue transmission regions	None	None	None

Woodruff et al. (2006) projected the spread of dengue in Australia as a result of increased temperatures on the basis of "no policy action" to reduce greenhouse gas emissions. Their conclusions were that strong policy action to reduce emissions would prevent further expansion of dengue fever (Woodruff 2006).

Rawlins et al. (2007) collected primarily response data and explored community knowledge of climate change issues as well as community willingness to help control dengue fever in the Caribbean. Understanding and awareness of climate and health issues were found to be high, but involvement was anticipated only to occur with greater levels of community persuasion.

None of the studies we reviewed had explored health system responsiveness to changes in dengue fever as a result of climate change. The majority of the studies focused either on the impacts of climate change on dengue fever outbreaks and patterns (Hales et al. 1999; Bultó et al. 2006), on the impacts of climate change policies on dengue fever distribution (Woodruff 2006), or on community knowledge and willingness to participate in vector control methods (Rawlins et al. 2007). Overall, while the awareness of potential vector control methods exists (Table 2), there is a clear gap in the literature about responding to changes in dengue fever as a result of climate change and also with regard to monitoring and evaluation.

TABLE 1
Vector Control Methods Discussed in Included Studies of Dengue Fever Review

Authors	Year	Develop preparedness plans	Assess preparedness efforts	Evaluate communication strategies	Evaluate public health interventions	Intersectoral collaboration	Reduce greenhouse gas emissions	Drug / vaccine development	Further research	Prevent importation of disease by travellers	Train health care providers	Educate Public	Protect natural biodiversity	Forecast climate	Improve data collection	Surveillance
Bulto et al.	2006					Yes								Yes		Yes
Campbell-Lendrum and Woodruff	2006															
Frumkin et al.	2008	Yes	Yes	Yes	Yes	Yes		Yes	Yes		Yes	Yes		Yes	Yes	Yes
Gubler et al.	2001				Yes			Yes	Yes		Yes	Yes		Yes		Yes
Hales et al.	1999															
Lifson	1996											Yes				Yes
Patz and Kovats	2002	Yes						Yes				Yes		Yes		Yes
Patz et al.	2000	Yes						Yes	Yes	Yes	Yes	Yes		Yes		Yes
Rawlins et al.	2007			Yes	Yes	Yes			Yes			Yes				
Rodriguez-Tan and Weir	1998							Yes			Yes					Yes
Sutherst	2004	Yes	Yes		Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Woodruff et al.	2006						Yes					Yes				Yes

3. METHODOLOGY

This study was carried out by principal investigators Prof Rifat Atun and Dr Pauline Brocard of the Imperial College London in collaboration with the World Health Organization (WHO) Centre for Health Development (WHO Kobe Centre – WKC), Japan. The researchers identified the need for an assessment tool for health system preparedness in the context of dengue fever and climate change. Therefore, the study focused on three components:

- A systematic review of the health plan preparedness for changes in dengue fever as a result of climate change (see Section 2 above);
- The development of a toolkit to assess preparedness; and
- A case study of Bangkok, Thailand.

This study is significant because understanding and exploring the gaps or bottlenecks in preparedness is critical to protecting communities from the increasing dengue fever threat. Research findings can inform, advise and guide countries and cities on how to increase their levels of preparedness.

This multidisciplinary, multi-method approach to assessment was primarily validated in a cross-sectional, cross-cultural setting. This work can inform interested researchers on the application of the toolkit, which has been successfully applied in Thailand. This study also assists in the evaluation of other cities' preparedness for changes in dengue fever due to climate change.

3.1 Toolkit Development

There are no current approaches for identifying the preparedness of national-capital city health systems for changes in dengue fever attributable to climate change. This toolkit was developed after carrying out systematic reviews and was based on the Systemic Rapid Assessment (SYSRA) and Systemic Rapid Assessment and Monitoring (SYSRAM) toolkits for tuberculosis and influenza developed by Professor Rifat Atun and his colleagues (Atun 2004, 2005; Coker 2004, 2006, 2007), and on other frameworks for evaluating public health system response to disasters including bioterrorism and heat waves (Landesman 2005; Bravata 2004; Bravata 2005; WHO 2005; Kovats 2006; Buehler 2004).

Although a number of guidelines and manuals exist for assessment, monitoring, and evaluation of vector control methods, they lack well-developed tools for enabling a response to climate-led variations in dengue fever (WHO 2003b, 2005, 2006a, 2006b). Despite the importance of an effective response to increasing incidences of dengue fever, no formally validated tool exists to perform a detailed assessment of preparedness. There is a dire need for a systemic, programmatic approach to analyzing preparedness to changes in dengue fever.

The specific goals of the toolkit are to analyze the organizational arrangements related to dengue fever, to investigate the capacity of health systems to respond to changes in dengue fever as a result of climate change, and to identify barriers and facilitators of effective response. The toolkit framework was developed by the researchers in collaboration with the WHO Centre for Health Development and was conceptualized after reviewing dengue fever control guidelines (WHO 2003b, 2005, 2006a, 2006b; Lloyd 2003), as well as the following:

- approaches for evaluating public health systems or programs (CDC 2001);
- public health responses to disasters (Landesman et al. 2005), such as bioterrorism (Bravata 2004; Bravata 2005), influenza pandemics (WHO 2005; Mounier-Jack 2006), and heatwaves (Matthies 2008; Kovats 2006);
- methods for early detection of outbreaks (Buehler 2004); and
- the Systemic Rapid Assessment Toolkit (SYSRA) (Atun RA 2004).

Since the topic is broad, and involves many key players in different settings, the identification of an optimal response plan for vector-borne diseases was necessary to help guide interviewers and to aid in the recognition of gaps in response plans.

The toolkit facilitates the recording of relevant information from national documents, epidemiological and weather data, and key informant interviews. These include key documents pertaining to climate change in the country, and ministry of health plans in relation to responses to health impacts of climate change. National and regional data and trends for incidence and prevalence, as well as mortality, are sought and analyzed for changes and variances. Long-term weather data are also analyzed to ascertain any changes and trends.

3.2 Interviews

The questions for the interview were developed using the existing toolkits and response plans. The list of questions is used as a guide for the interviewer, and the questions asked depend largely on the knowledge and expertise of the person being interviewed. The progression of questions is dependent on the answers given by the respondent.

The process of using the toolkit involves the purposeful sampling of key actors involved in various health system functions at different administrative levels (e.g., national vs. regional). A mix of respondents from different organizations and backgrounds is required for a robust, qualitative response. All information provided by interviewees was confidential and non-attributable. The interviews were recorded in writing or via audiotape with the permission of the interviewee. Later, the interviews were transcribed verbatim for detailed thematic analysis. Initially, an optimal response plan was created with key questions to assess the preparedness of health system to changes in dengue fever as a result of climate change. Having previously developed the dengue preparedness and climate change toolkit, the Bangkok case study served as practical test of our work. The toolkit has since been reviewed and revised.

4. BANGKOK CASE STUDY

The toolkit was tested on the Thai health system. Thailand was chosen for the case study because it is globally renowned for its well-functioning health system. Thailand is a middle-income developing country with an integrated health system and it is also being affected by climate change. In theory, because Thailand has integrated a number of diverse programs into its health system, we postulate that the country is relatively well-positioned to respond to climate change related shifts in dengue fever.

With the help of the WHO Centre for Health Development, the WHO Regional Office for South-East Asia, and the WHO Country Office Thailand, meetings were organized with key staff members at the Ministry of Public Health, Bangkok Metropolitan Administration (BMA), Faculty of Tropical Medicine and Faculty of Science of Mahidol University, and various Health Offices in the Ayutthaya province. Mahidol University was chosen because it is one of the leading universities in tropical medicine in Thailand and is home to the Regional Centre for Tropical Medicine for Southeast Asian Ministers of Education Organization (SEAMEO). Moreover, the University boasts several WHO Collaborating Centres.

In addition to understanding how a health system might be able to respond to changes in dengue fever as a result of climate change, the aim of this exploratory case study is to identify how a response might be initiated in the Thai health system as a result of perceived changes in the environment. Other key questions were: What systems are in place to cope with possible increases in incidence of dengue fever as a result of climate change? What are the thresholds? Who will make the decisions? To what extent is climate change associated with changes in disease incidence?

The interviews were conducted at multiple levels and involved multiple stakeholders. The researchers followed a triangulation and inductive approach as they were constantly discussing findings between meetings. Meetings were held in Bangkok with a total of 48 people, and included the following key informants from the Thai health system: the Director of the Bureau of Vector-borne Diseases at the Ministry of Public Health, Directors of Disease Control Division at several District Health Offices, the Director of SEAMEO TROPMED and the Dean of Faculty of Tropical Medicine, and a National Professional Officer at the WHO Thailand Office. The meetings were facilitated by Prof Rifat Atun and the interviews were sound-recorded and transcribed. After the meetings, Prof Atun and Dr Brocard discussed observations and identified key results, strengthening the case study. The meetings were focused on interpreting how Thailand is initiating a response to increased incidences of dengue fever as a result of climate change. Additionally, meetings were organized with provincial health offices to explore levels of understanding and awareness of these issues in the field. All the meetings were audio recorded with permission, and later transcribed. Direct quotes were referenced by institution name in order to maintain the anonymity of interviewees.

District-level dengue fever data were provided to the research team after the meetings. Because of the scale of the datasets, and because they did not include climate data, we were unable to conduct complex statistical analysis to identify underlying trends in seasonality and dengue incidence.

4.1 Perceived Impacts of Climate Change

Data show that rain and dengue fever are highly correlated (Faculty of Tropical Medicine). Dengue incidence increases and decreases every 1-3 years (Faculty of Tropical Medicine, WHO Thailand Office). This could be due to population immunity or different serotypes that cause more cases (Ayutthaya Provincial Office). In 2008 the Thai Ministry of Health reported that the number of cases increased by 40% compared to 2007. The Ministry has been issuing warnings about this since February 2008, as this is the dry season and usually very quiet (Faculty of Tropical Medicine).

Temperature has increased. It is difficult to say if this has affected the number of cases. However, scientific evidence shows that an increase in temperature cuts the disease incubation period, increasing the time in which infection can occur. Research also shows that the vector develops more quickly (Bureau of Vector-borne Diseases).

In Thailand, dengue outbreak alerts may begin to last all year as the disease becomes less seasonal. In 2008, the country dengue alert started in January, which is very unusual (WHO Thailand Office). The research community is uncertain about whether this trend is due to climate change or not. However, future research is taking us in the direction towards and analysis of this phenomenon (Sena District Health Office).

Our difficulty is that we cannot predict. We have not tried to collect the information to see what is the component contributed by the weather change (Faculty of Tropical Medicine). We do not know about decomposition analysis (controlling for seasonal cycles and longer term 2-3 year cycles (Bureau of Vector-borne Diseases).

4.2 Health System Preparedness

In Thailand, all diseases, except malaria, are integrated into health system concerns (Bureau of Vector-borne Diseases and WHO Country Office Thailand). Not all cases of dengue fever are reported, because only 10% of all patients have symptoms and/or go to a health centre. The other 90% of infected individuals do not go to a health centre because they experience mild to no symptoms (Bureau of Vector-borne Diseases). 100% of dengue hemorrhagic fever (DHF) cases are recorded because all the patients go to hospital (Faculty of Tropical Medicine). However, there are no resources for active case detection at the Sena District Health Office. The Faculty of Tropical Medicine has done a serum survey of schoolchildren, identifying the presence of immunoglobulin G (IgG) antibodies. In schools, 80% of children had IgG present, which indicates that a high proportion of students were either immune, ill and asymptomatic, or had only mild symptoms (Faculty of Tropical Medicine).

In Thailand, health systems workers claim that incidences of dengue fever are currently underestimated because patients with mild or no symptoms do not go to hospital. This is an issue that needs to be addressed via mobilization of resources for active case detection. If the ratio of reported versus unreported cases was estimated then it would be possible to have a better estimate of dengue fever incidence. Interviewees stressed the difficulty of managing something that is not accurately measured.

4.3 Thresholds and Response

Our research found that there exists a threshold for response that is related to the number of reported dengue infections. If the number of cases for cold season (November to January) is high, as it was in 2008, then there is likely to be a problem in the following hot season (April to August). With more mosquitoes, there are more larvae and the number of dengue cases during the hot season will be high (Bureau of Vector-borne Diseases).

In Thailand, a dengue warning is issued when the rainy season starts. However, there are no specific thresholds for when a warning is issued (WHO CO Thailand). The dengue warning system was developed 6-7 years ago. Currently, the Thais are working to modify it for better detection (Faculty of Tropical Medicine).

In Thailand, the Surveillance Rapid Response Team (SRRT) deals with the response phase of all disease outbreaks including dengue fever (Bureau of Vector-borne Diseases). When there is as little as one case, the team is deployed to control spreading by spraying to reduce the number of infected mosquitoes within 100m. SRRT also works to mitigate outbreaks by control by emptying containers that may house larvae, through community education, and by distributing bed nets (Bureau of Vector-borne Diseases). Interview respondents at the Ayutthaya Provincial Office stressed that for every single dengue case they use all available resources during response (Ayutthaya Provincial Office). Said one respondent, "If one district has a greater number of cases, we increase the number of teams in that area. If more problems emerge, we mobilize other health workers. We have a very flexible system in place (Ayutthaya Provincial Office)."

In September of 2008, the Sena District Health Office was faced with an outbreak of 15 dengue cases. They responded by calling a war room meeting, and continued with monthly war room meetings as the outbreak trend continued to increase. In addition, they deployed extra response and mitigation teams to help affected regions, enlisted the help of volunteers, and engaged communities in health education. However, dengue incidences continued to increase. In response to this phenomenon one respondent said, "We did not understand why it happened. We put all of our efforts in. We think there was not enough participation by the community (Sena District Health Office)."

When asked about whether or not they have a comprehensive response plan for an increase in dengue as a result of climate change the majority of respondents answered 'no'. The Ayutthaya Provincial Office mentioned that competing priorities are holding back the development of a climate change response plan. "Dengue has to be visible to gain public attention and the collaboration of health workers and the public" one respondent remarked. "Communication is not a problem. People are aware. But the difficulty is changing behaviour."

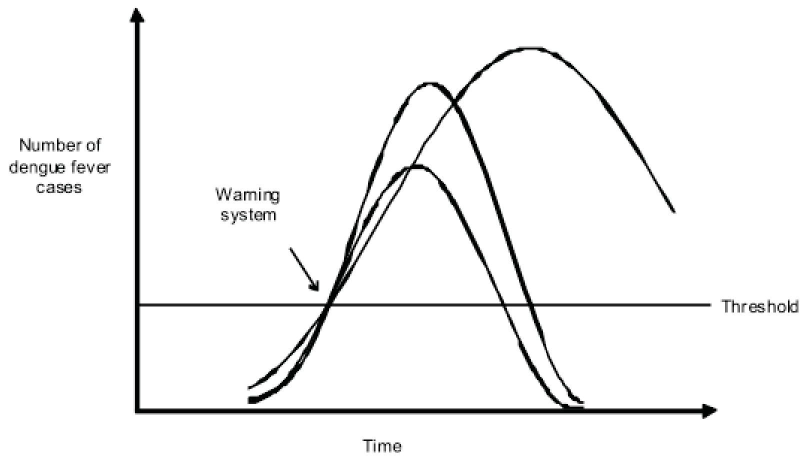
The Faculty of Tropical Medicine asserted that climate change response plans must be a Ministry policy. "The Ministry already prepares disaster management plans for climate change and national disaster management plans for other diseases," one respondent said. "Now they recognize disasters like storms. They are aware of climate change. But for dengue they have no system." According to interviewees at the Faculty of Tropical Medicine, policy makers at the Ministry of Health do not recognize climate change as important because the science of climate change and health is still in the research stage.

Because there are no response plans in place for increases in dengue fever as a result of climate change, we chose to ask questions about the policy and planning infrastructures in place for response to disasters and other diseases. Our interviews showed that members of the Thai health system are learning from disaster management strategies. The Faculty of Tropical Medicine held a table-top exercise after the tsunami. The Chatuchak District Health Office learned about response strategies from floods, fires, collapsed buildings, and bird flu epidemics. For example, after the SARS outbreak in Asia, the Bureau of Vector-borne Disease trained every district team, regional office and provincial team in response and mitigation. They also conducted risk simulations to better plan for outbreak response. "Simulations are held once a year," said one respondent. "We have evaluated simulations for avian flu and plane crashes. We have to budget for this, for the funding of every province, and for capacity building." Respondents stressed that ultimately, the quality of response and mitigation activity depends on the capacity of the local people.

As a result of climate change, not only is the number of dengue cases increasing, but the curve of dengue incidence may also be changing (Figure 3). If the Thai health system continues with business as usual, response mode will remain unable to decrease incidences of dengue over time. At some point the Thai health system will need to mount a large-scale response instead of increasing incrementally with each case.

There are several bottlenecks to triggering effective response that have been identified. These include community resilience, the pace of the decision-making process, and drug supply issues. Currently, the Thai health system can cope with

FIGURE 3
Projected Scenarios of Dengue Fever Incidence



a 10-20% increase in cases. However, it would need to develop flexible resources to respond to an increase in cases of greater than 20%. It is not clear who will make the decision to respond. This may lead to significant communication issues during mitigation and response planning.

The Ministry of Health and local health offices are not always aware of the potential of climate change to dramatically transform the disease patterns of dengue fever. As we learned from the interviews, they have other priorities. “We can take care of the problem,” claims a respondent at the Faculty of Tropical Medicine. “It is a question of prioritisation if is a threat or not. It is not thought of as urgent.”

The Thai health system has protocols and simulations for heat waves and SARS, and so there are the systems in place, and the resources and capabilities to develop response plans. However, as can be seen from French heat wave in 2003 and the Brazil dengue outbreak in 2007, even the best health care systems can have high mortality rates if proper response planning is not in place. In the absence of response plans it takes longer for decisions to be made and for resources to reach the disaster areas. The Thai health system needs to translate the lessons learned from other disaster response situations to their management of dengue fever.

5. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

There are many peer-reviewed papers reflecting an awareness of the potential changes in dengue fever from climate change. However, there are no papers looking specifically at the preparedness of health systems and plans to respond to changes in dengue fever reasonably attributable to climate change. We developed a toolkit to assess the preparedness of health systems to changes in dengue fever from climate change.

Moreover, our Thailand case study illuminated some of the challenges, current strategies, and capacity of health care systems to respond to climate change related health threats. Thailand has a truly complex and sophisticated surveillance system for dengue fever. Overall, response to cases is a priority, and often times skilled response teams are deployed to the site of every case reported. However, with this reactive vector control strategy there is no system in place to identify long-term changes in dengue fever, and no response plan for changes as a result of a warmer climate.

In Thailand there is strong collaboration, innovation and enthusiasm at health centre level. However, there is an organizational issue in response because the system is so complex. There are good surveillance systems in place, but there are organizational issues in the field.

This paper is the first to explore how the Thai health system would cope with a sudden increase in dengue fever due to climate change. This is a significant initiative in encouraging awareness of this issue and the need for the Ministry of Health to create a response plan. Moreover, the case study provided a forum for the evaluation of the health system assessment toolkit. The toolkit can be applied to different countries as a Rapid Assessment Test. Gaps in health systems could be more easily identified, and guidelines could be formulated to aid preparedness to changes in dengue fever outbreaks.

This study was carried out as a collaborative effort between the Imperial College Consultants Ltd and the World Health Organization. It explored a new territory, followed robust methodology, developed a new toolkit and evaluated it with an exploratory case study in Bangkok. Systematic reviews were carried out to a high standard, following the Cochrane guidelines.

Ultimately, policy-makers need to become aware of the risk associated with climate change and dengue fever. Only then will they be able to prioritize the development of comprehensive response plans.

This study illuminates a number of potential research directions. Thai disease and weather data needs to be collected and analyzed in order to identify key trends in incidence and virulence. The results of these empirical studies can be used to further engage policy-makers. In addition, Thai health care infrastructure will benefit greatly from further analysis of health system preparedness in the context of malaria and climate change. Robust case studies should be carried out to further validate the toolkit. Future research will help identify globally applicable guidelines for how to develop response plans for increases in dengue fever.

References

Altizer, S. et al. 2004. "Seasonal Dynamics of Mycoplasmal Conjunctivitis in Eastern North American House Finches. *The Journal of Animal Ecology* 73 (2): 309.

Atun, R. A. 2005. "Barriers to Sustainable Tuberculosis Control in the Russian Federation Health System." *Bulletin of the World Health Organization* 83: 217.

______. 2004. "A Framework and Toolkit for Capturing the Communicable Disease Programmes within Health Systems: Tuberculosis Control as an Illustrative Example." *The European Journal of Public Health* 14 (3): 267.

______. 2005. "Implementing WHO DOTS Strategy in the Russian Federation: Stakeholder Attitudes." *Health Policy and Education* 74 (2): 122.

Bravata, D.M. 2005. "Challenges in Systematic Reviews: Synthesis of Topics Related to the Delivery, Organization, and Financing of Health Care." *Annals of Internal Medicine* 142 (12 Pt 2): 1056.

Bravata, D.M. et al. 2004. "A Conceptual Framework for Evaluating Information Technologies and Decision Support Systems for Bioterrorism Preparedness and Response." *Medical Decision Making* 24 (2): 192.

Buehler, J.W. et al. 2004. "Framework for evaluating public health surveillance systems for early detection of outbreaks." *Morbidity and Mortality Weekly Report. Recommendations and Reports* 53: 1.

Bultó, P.L., Rodríguez A.P., Valencia A.R., Vega N.L., Gonzalez M.D., and Carrera A.P. 2006. "Assessment of Human Health Vulnerability to Climate Variability and Change in Cuba." *Environmental Health Perspectives* 114 (12): 1942.

Campbell-Lendrum, D., and Woodruff R. 2007. *Climate Change: Quantifying the Health Impact at National and Local Levels.* World Health Organization.

______. 2006. Comparative Risk Assessment of the Burden of Disease from Climate Change. *Environmental Health Perspectives,* 114 (12): 1935.

CDC. 2001. "Updated Guidelines for Evaluating Public Health Surveillance Systems." Recommendations from the Guidelines Working Group. MMWR. 50 (RR13).

Chen, L.H., and Wilson M.E. 2005. "Non-Vector Transmission of Dengue and Other Mosquito-Borne Flaviviruses." Report number: 29.

Chiaravalloti, Neto F. 2007. Dengue Control Program in São José do Rio Preto, São Paulo State. "Brazil: Problems with Health Agents' Work and Population Adherence." *Cadernos De Saúde Públic,* 23 (7): 1656.

Coker, R. 2006. "Pandemic Influenza Preparedness in the Asia–Pacific region." *Lancet, the* 368 (9538): 886.

______. 2007. UK Preparedness for Pandemic Influenza. *BMJ.Com* 334 (7601): 965.

______. 2004. Untangling Gordian knots: Improving Tuberculosis Control through the Development of 'Programme Theories.'' *The International Journal of Health Planning and Management* 19 (3): 217.

Frumkin, H., Hess J., Luber G., Malilay J., and McGeehin M. 2008. "Climate Change: The Public Health Response." *American Journal of Public Health* 98 (3): 435–45.

Fukuda, K. 2008. "Age–Period–Cohort Decomposition of US and Japanese Birth Rates." *Population Research and Policy Review* 27 (4): 385.

Gemperli, A. et al. 2006. "Mapping malaria transmission in West and Central Africa." *Tropical Medicine International Health* 11 (7): 1032.

Gubler, D.J. 2001. "Climate Variability and Change in the United States: Potential Impacts on Vector and Rodent-Borne Diseases." *Environmental Health Perspectives* 109 (Supplement 2): 223.

Gubler, D.J., Reiter P., Ebi K., Yap W., Nasci R., and Patz J.A. 2001. "Climate Variability and Change in the United States: Potential Impacts on Vector- and Rodent-Borne Diseases." *Environmental Health Perspectives* 109 (Supplement 2): 223.

Hales, S., Weinstein P., Souares Y., and Woodward A. 1999. "El Nino and the Dynamics of Vectorborne Disease Transmission." *Environmental Health Perspectives* 107 (2): 99–102.

Hales, S. 2002. "Potential Effect of Population and Climate Changes on Global Distribution of Dengue Fever: An Empirical Model." *Lancet, the* 360 (9336): 830.

Khasnis. 2005. "Global Warming and Infectious Disease." *Archives of Medical Research* 36 (6): 689.

Kovats, R.S. 2006. "Heatwaves and Public Health in Europe." *The European Journal of Public Health* 16 (6): 592.

Landesman, L.Y., Malilay J., Bissell R.A., Becker S.M., Roberts L., and Ascher M.S. 2005. "Roles and Responsibilities of Public Health in Disaster Preparedness and Response." In *Public Health Administration,* ed. Novick L.F. and Mays G.P. 646 – 708.

Lifson, A.R. 1996. "Mosquitoes, Models, and Dengue." *Lancet, the* 347 (9010): 1201.

Lindsay, S.W., and Birley M.H. 1996. Climate Change and Malaria Transmission." *Annals of Tropical Medicine and Parasitology* 90 (6): 573.

Lloyd, L.S. 2003. "Best practices for dengue prevention and control in the Americas. Environmental Health Project." Report number: Strategic Report 7.

Lott, S. (2007) *Tsunami's impact on Thailand*. http://academic.evergreen.edu/g/grossmaz/LOTTHN/.

Martens, W.J.M. et al. 1995. "Potential Impact of Global Climate Change on Malaria Risk." *Environmental Health Perspectives* 103 (5): 458.

Matthies, F., Bickler G., Cardenosa Marin N., and Hales S. 2008. *Heat-Health Action Plans Guidance.* EURO Nonserial Publication.

Medronho, R. 2008. "Challenges for Dengue Control in Brazil." *Cadernos De Saúde Pública* 24: 948.

Mounier-Jack S., and Coker J.R. 2006. "How prepared is Europe for Pandemic Influenza? Analysis of National Plans." *Lancet, the* 367 (9520): 1405.

Pascal, M. 2006. "France's Heat Health Watch Warning System." *International Journal of Biometeorology* 50 (3): 144.

Patz ,J.A., and Kovats R.S. 2002. "Hotspots in Climate Change and Human Health." *BMJ* 325 (7372): 1094–8.

Patz, J. A., McGeehin M., Bernard S.M., Ebi K., Epstein P., Grambsch A., Gubler D.J., Reiter P., Romieu I., Rose J.B., Samet J.M., and Trtanj J. 2000. "The Potential Health Impacts of Climate Variability and Change for the United States: Executive Summary of the Report of the Health Sector of the U.S. National Assessment." *Environmental Health Perspectives* 108 (4).

Rawlins, S.C., Chen A., Rawlins J.M., Chadee D.D., and Legall G. 2007. "A Knowledge, Attitude and Practices Study of the Issues of Climate Change/Variability Impacts and Public Health in Trinidad and Tobago, and St Kitts and Nevis." *West Indian Med J* 56 (2): 115.

Rodriguez-Tan, R.S., and Weir, M.R. 1998. "Dengue: A Review." *Tex Med.* 94 (10): 53.

Silawan, Tassanee. 2008. "Temporal Patterns and Forecast of Dengue Infection in Northeastern Thailand." *The Southeast Asian Journal of Tropical Medicine and Public Health* 39 (1): 90.

Smith, T. et al. 1995. "Mapping the Densities of Malaria Vectors within a Single Village." *Acta Tropica* 59 (1): 1.

Sutherst, R.W. 2004. "Global Change and Human Vulnerability to Vector-borne Diseases." *Journal of Clinical Microbiology* 17 (1): 136.

Tanser, F. C. 2003. "Potential Effect of Climate Change on Malaria Transmission in Africa." *Lancet, the* 362 (9398): 1792.

The Cochrane Collaboration. http://www.cochrane.org/index.htm.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2005. "International Coordination Meeting for the Development of a Tsunami Warning and Mitigation System for the Indian Ocean within a Global Framework." Intergovernmental Oceanographic Commission. Report number: 196.

Vandentorren, S., and Empereur-Bissonnet, P. 2005. "Health Impact of the 2003 Heat-Wave in France." In *Extreme Weather Events and Public Health Responses,*. ed. Kirch W., Bertollini R. and Menne B., 8.

WHO (World Health Organization). 2003a. *Climate change and human health - risks and responses*. pp. 237-263.

______. 2003b. *Guidelines for Dengue Surveillance and Mosquito Control.* 2nd edition.

______. 2004a. *Disease Information.* http://www.who.int/tdr/diseases/dengue/diseaseinfo.htm.

______. 2004b. *Fourth Ministerial Conference on Environment and Health*. Declaration.

______. 2005. *WHO Checklist for Influenza Pandemic Preparedness Planning.*

______. 2006a. *Guidelines for the Treatment of Malaria.*

______. 2006b. *Malaria Vector Control and Personal Protection: Report of a Who Study Group* 936.

______. 2008. *Dengue and Dengue Haemorrhagic Fever. Fact Sheet No 117.* http://www.who.int/mediacentre/factsheets/fs117/en/.

______. 2008. *Protecting Health in Europe from Climate Change.*

______. 2008. *WHO Climate Change and Health Program Activities.* http://www.who.int/globalchange/climate/activities/en/.

______. 2008. *World Health Day 2008: Protecting Health from Climate Change.* http://www.who.int/world-health-day/en/ [Accessed 05/03/2008].

WHO (World Health Organization) Kobe Centre. 2008. *Climate Refugees, Dengue Mosquitoes and Killer Heat — Top Scientists Speak out at WHO Kobe Centre's World Health Day Symposium*. http://www.who.or.jp/whd.html.

World Bank. 2008. *At Last, a Practical Guide to Climate-proof Our Cities.* http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/0,,contentMDK:21863994~pagePK:146736~piPK:146830~theSitePK:226301,00.html.

Woodruff, R. 2006. "Action on Climate Change: The Health Risks of Procrastinating." *Australian and New Zealand Journal of Public Health,* 30 (6): 567.

Ye, Y. et al. 2007. "Effect of Meteorological Factors on Clinical Malaria Risk among Children: An Assessment Using Village-Based Meteorological Stations and Community-Based Parasitological Survey." *BMC Public Health* 7 (1): 101.

EPILOGUE

Perspectives from the 5th Urban Research Symposium

To do justice to the wealth of research and discussion that took place during the 5th Urban Research Symposium, this final chapter condenses the findings from a selection of 42 symposium papers. Written by leading researchers and academics, this synthesis is organized into four sections, reflecting the five thematic clusters of the symposium: (1) models and indicators for measuring impact and performance, (2) infrastructure, the built environment, and energy efficiency, (3) institutions and governance, and (4) economic and social aspects of climate change in cities (this last section merged from two of the symposium clusters).

Models and Indicators to Measure Impact and Performance

Anu Ramaswami and Joshua Sperling

Scientific knowledge and accurate measurement techniques to address climate action in cities are only now catching up with the magnitude of the urban climate challenge. This thematic area reviews key gaps in our knowledge to date and summarizes available models, field measurement, and indicators in two main areas: (1) energy-use and greenhouse gas (GHG) emissions associated with cities and (2) understanding climate risks, vulnerabilities, and adaptation strategies in cities.

Significant transboundary exchange of energy and materials occurs between cities and surrounding hinterland areas. These exchanges are reflected in trade and transport among cities and in large-scale infrastructure such as the power plants that serve cities but are often located outside city boundaries. Such transboundary activities confound measurements of GHG emissions at the city scale and raise many important questions, such as the following:

- What are the best methods to measure GHG emissions from cities when human activities in cities transcend the small geographic-administrative boundary of cities?
- What are the principles by which GHG emissions are allocated to urban residents? How is trade between cities, national and international, incorporated into GHG accounting?
- How can city-scale GHG accounting techniques be more policy relevant and compatible with existing methodologies established to promote carbon trading?
- Can city-scale GHG emissions be benchmarked on a per capita basis and compared with national-scale GHG emissions and with other cities?
- What do we know about current baseline energy-use benchmarks in buildings and transport sectors in cities across the world?

- How can urban design—the layout and choice or urban materials—enhance GHG mitigation in the buildings sector?

In the commissioned research paper "Greenhouse Gas Emission Baselines for Global Cities and Metropolitan Regions," Kennedy, Ramaswami, Carney, and Dhakal address the question of GHG accounting to incorporate transboundary urban activities. The paper reviews key methodologies for measuring GHG emissions from cities and covers multiple activity sectors—energy use in stationary and mobile combustion addressing building and transport sectors, industrial nonenergy process emissions, waste emissions, and land-use change. A major breakthrough of this paper is to harmonize different methods in the literature for estimating GHG emissions associated with cities and to develop a resulting consistent methodology that is applied to 43 cities across the globe. The methodology distinguishes between energy-use and direct GHG emissions within urban boundaries (Scope 1 emissions) computed consistently with Intergovernmental Panel on Climate Change (IPCC) methods, transboundary contributions associated with electricity generation for use within cities (Scope 2), and emissions associated with marine and airline travel from cities (Scope 3). The paper demonstrates that data are available, and that overall and per capita GHG emissions can indeed be computed in a consistent manner for numerous cities across the world. A key finding of the paper is that required reporting on Scope 1 and Scope 2 emissions, supplemented with optional reporting of Scope 3 items, offers a robust methodology for representing GHG emissions associated with urban activities.

Growing interest exists in assessing spatial variation in GHG emissions both within urban areas as a function of urban form and across the urban-rural gradient. For example, in the paper "Energy Consumption and CO_2 Emissions in Urban Counties in the United States," Parshall, Hammer, and Gurney have mapped direct fossil energy-use and GHG emissions associated with 157 urban areas in the United States; their paper enables analysis of geospatial variations in transportation-related GHG emissions with parameters such as population density in a case study of the New York City metropolitan area. Because the Vulcan data product used in the analysis does not track end use of electricity, overall energy use in the building stock could not be compared geospatially. However, the paper demonstrates the power of spatial visualization. Future work in this area of spatial mapping of GHG emissions will require more detailed utility-derived data on electricity use at higher resolutions, including the neighborhood level.

The commissioned paper by Gupta and Chandiwala, "A Critical and Comparative Evaluation of CO_2 Emissions from National Building Stocks," demonstrates the importance of benchmarks for understanding and mitigating GHG emissions from buildings. Their paper provides a comprehensive analysis of energy-use benchmarks and GHG emissions from the building stocks in the United States, United Kingdom, and India as well as insightful comparisons between the three nations. The paper examines end uses of energy and reviews technology and policy strategies to reduce GHG emission from the urban building stocks in the three countries. Changes in energy consumption profiles are assessed from the 1990s into the 21st century, and quantitative metrics are developed to represent energy-use intensities in the three nations. Design and policy strategies applied in the three countries to reduce GHG emissions from the urban building stock are surveyed and compared.

In the construction of new buildings and neighborhoods, a variety of factors—including density and form of buildings, orientation, building materials, and landscape characteristics—all play an important role both in reducing energy use in buildings as well as mitigating the urban heat island effect. In "Mitigating Urban Heat Island Effect by Urban Design," Bouyer, Musy, Huang, and Athamena provide a synthesis of some of the research streams addressing how urban form (characterized by the spatial proportion and arrangement of buildings in a neighborhood or block) along with the selection of rooftop materials determines surface albedo, which in turn affects energy use in buildings and the urban heat island effect. The authors propose preliminary indicators of urban form and effective albedo as design guides for designing blocks or neighborhoods with reduced energy use and hence lower GHG emissions. The utility of the method is demonstrated qualitatively using simulations of two city blocks in France.

The same spatial scale issues that render GHG accounting in cities challenging also arise in assessments of climate-related vulnerabilities at the city scale. Currently, climate projections for the present century are provided by the IPCC, most recently in its Fourth Assessment Report, but these have several limitations that inhibit their application at the city scale. First, the projections are typically provided at coarse spatial (such as hundreds of kilometers) and temporal (such as monthly) scales, and decisions have to be made at finer regional or local scales and require information at submonthly time scales. Second, the projections provide average temperature and precipitation, whereas vulnerability assessments require a suite of climate information (such as wet or dry and hot or cold spells, extreme events, and the like). Last but not least, they do not capture urban features, and near-term decadal projections are less skilful than long-term projections. Furthermore, climate model projections have not been linked systematically with distribution of vulnerabilities and societal capacities for adaptive governance.

Thus, key questions in the area of climate adaptation at the city scale include issues such as the following:

- What are the best methods to downscale climate models while integrating key urban features such as anthropogenic heat fluxes and urban surface characteristics?
- What is the range of extreme events that can be expected in cities as a consequence of climate change, and how are they different from larger-scale projections?
- What are the available frameworks for translating climate impacts into hazards, risks, and adaptive strategies in cities, as planners recognize the disproportionate impacts on the most vulnerable populations?

Climate change is expected to generate a range of impacts that cities must address in adaptation planning, including more frequent extreme heat events, droughts, extreme precipitation and storm events, sea-level rise, and changes in disease vectors. Such impacts can affect public health, ecosystems, and the many infrastructure systems, including water, energy, transportation, and sanitation systems, that serve cities. To better characterize these impacts, climate models downscaled to the urban scale are gaining more attention. McCarthy and Sanderson are leading the work in this arena, as presented in their paper "Urban Heat Islands: Sensitivity of Urban Temperatures to Climate Change and Heat Release in Four European Cities" on preliminary results from downscaling regional climate models (RCMs) using an improved urban surface scheme (MOSES2). Their results indicate that when finer-scale urban layers are included—particularly anthropogenic heat fluxes and surface characteristics of urban areas—more extreme temperature impacts may be seen in cities than previously projected. For example, the number of hot nights in London for the decade of 2050 is projected to be three times greater if urban areas and anthropogenic heat release are included in model simulations, when compared with rural areas.

A holistic framework that integrates climate impacts with associated climate hazards in cities, resulting vulnerabilities, and society's adaptive capacity is offered in the commissioned paper by Mehrotra and others, "Framework for City Climate Risk Assessment." The paper presents a detailed review of the body of literature on hazards, risks and vulnerabilities, and adaptive capacity, woven together in a comprehensive framework for climate adaptation in cities. The three-component framework is developed and tested in four case study cities: Buenos Aires, Delhi, Lagos, and New York City and covers a range of hazards, including sea-level rise for coastal cities and extreme heat events for landlocked tropical cities such as Delhi. The authors note that the vulnerabilities identified in each city suggest differential impacts on poor and non-poor urban residents as well as sectorally disaggregated implications for infrastructure and social well-being. In response, they highlight successful policies and programs at the city level that aim to reduce systemic climate risks, especially for the most vulnerable populations. A four-track approach to risk assessment and crafting of adaptation mechanisms is proposed (including assessment of hazards, vulnerability, adaptive capacity, and emerging issues) so that city governments can respond to climate change effectively and efficiently.

Although the papers in this thematic area represent recent developments in the field, research is progressing fast. Knowledge sharing among researchers and between researchers and practitioners is needed as new knowledge, measurement tools, and appropriate indicators are developed. Currently, there is no single place where city-scale climate change indicators and metrics are located. A first attempt at putting such information together in one database is discussed by McCarney in the last commissioned paper in this thematic area, "City Indicators on Climate Change." McCarney describes the process of developing a standardized set of city indicators, which includes a full range of city-scale climate-related metrics, addressing GHG emissions, mitigation, adaptation, vulnerability, and resilience, while also measuring city services and quality of life. The outputs of the Global City Indicators Program can be expected to respond continuously to new and improved methods of measuring city-scale GHG emissions, sectoral energy use, climate impact projections, and climate adaptation capacity.

Infrastructure, the Built Environment, and Energy Efficiency

Sebastian Carney and Cynthia Skelhorn

Cities are both large energy consumers and large GHG emitters. The energy consumption of a city is due, in part, to its infrastructure, building stock, culture, economic makeup, and population densities. In addition to the energy directly consumed by cities, we should recognize a wide range of emissions associated with the production of the goods and services that are consumed within cities but that may have been produced elsewhere.

This thematic area brings together examples of research from around the world on how cities may decarbonize over the coming years and decades. When planning for reducing GHG emissions, cities must recognize their current emissions sources and how they may seek to reduce these emissions, without increasing emissions elsewhere. With the global population expected to increase further in coming decades, and with much of this growth expected to take place in cities, how future populations live, work, and travel will determine the energy used to perform these tasks and, therefore, the significant part of their potential emissions.

The application of mitigation policies at the city scale remains in its infancy, although targets for GHG reductions and (or through) renewable energy implementation are regularly touted—the policy linked to delivering the targets does not always enjoy the same clarity. As a consequence, it is important to learn from those cities that have begun to implement change. This is taken forward in "A Comparative Analysis of Global City Policies in Climate Change Mitigation" by Croci, Melandri, and Molteni and in "A Comparative Study of Energy and Carbon Emissions Development Pathways and Climate Policy in Southeast Asian Cities" by Phdungsilp. The former considers a range of the world's global cities, whereas the latter concentrates on Southeast Asian cities.

These analyses are particularly complemented by the detailed work of van den Dobbelsteen and others in their paper on the REAP (Rotterdam Energy Approach and Planning) methodology, "Towards CO_2 Neutral City Planning—The Rotterdam Energy Approach and Planning (REAP)." This team modeled the current and potential future energy requirements of Rotterdam and combined it with available renewable energy resources within the city. The methodology follows established principles of mitigation, namely, measuring energy consumption, establishing areas for reduction, and minimizing waste flows. This structured approach, when considered with the wider documentation that exists online, affords a variety of graphical ways to communicate to wide audiences the types of changes necessary to deliver emissions reductions over differing time scales.

A city-level mitigation strategy is inevitably a function of its parts, with buildings contributing a sizeable component of a city's energy consumption. This requires investigating options for reducing energy consumption in the buildings sector in different contexts and creating a situation where buildings, both existing and future, may be considered "more sustainable." The transition to this point will vary across cities. The future energy consumption of a building is likely to be driven by a series of factors, including behavior, building design, and future climate. Kershaw and Coley demonstrate the impact of the latter point by applying a set of existing climatic scenarios to a set of differing building designs in "Characterizing the Response of Buildings to Climate Change." Their research demonstrates the need for building designs to be able to control their internal temperatures with a variable outside temperature and highlights the importance of existing policies on building design on both near-term (2020) and long-term (2080) energy consumption and wider climatic resilience.

The amount of energy consumed by a building should not necessarily be considered in isolation. A building has wider impacts associated with its upkeep that are not always included in energy balances, water being a particular example. With water becoming scarcer, utilizing rainwater for particular functions in buildings may lead to an overall reduction in energy consumption. Schmidt presents four demonstration projects in Berlin and provides wider insights with respect to rainwater utilization in "A New Water Paradigm for Urban Areas to Mitigate the Urban Heat Island Effect." This wider impact of buildings is taken further in "Indicators to Assess the Sustainability of Building Construction Processes" by Floissac and others, who consider the emissions impact of a building's entire life, from construction to demolition. Taken together, the papers in this area reaffirm our understanding of the key role of future building design and retrofitting of the existing building stock when considering both mitigation and adaptation—as well as the synergies between the two.

After buildings, the transport sector is a key user of energy in cities. The energy consumption of both sectors is influenced by how a city is designed. A variety of approaches may be taken to reduce emissions from road transport within cities, which pertain to both demand- and supply-oriented measures. Bertaud, Lefevre, and Yuen consider both types of measures as they present a study on the relationships between GHG emissions, urban transport policies and pricing, and the spatial form of cities in the commissioned paper "GHG Emissions, Urban Mobility, and Efficiency of Urban Morphology." They suggest that price signals are the main driver of technological change, transport modal shifts, and land-use regulatory changes. The use of road transport within cities is also affected by other forms of available transportation, as well as travel to and from a city. Recognizing this, the paper by Ravella and others, "Transport Systems, Greenhouse Gas Emissions, and Mitigation Measures," analyzes GHG emissions mitigation measures for different modes of land transport within cities and wider interurban networks in Argentina.

Individual aspects of a city will each provide part of the mitigation solution, but they must be consistent with one another to deliver the best outputs. This potentially requires a framework for assessing the current emissions sources and how each may contribute to a city's emission reduction. In "Getting to Carbon Neutral," Kennedy and others establish measures of cost effectiveness for reducing GHG emissions from 22 city case studies.

The issue of adaptation is perhaps deemed "closer to home" than mitigation, because it has a clear local impact, rather than a more global impact. Penney, Ligeti and Dickison, in their paper "Climate Change Adaptation Planning in Toronto," document Toronto's process for creating an adaptation strategy and framework document and reflect on barriers to integration with existing city plans and programs. They note the specific departments and programs involved as well as the process by which adaptation strategies were incorporated into these, but they also note barriers to implementation. In a very captivating example related to addressing urban form, Carbonell and Meffert assess large-scale ecosystem restoration, flood protection, jurisdictional advocacy and oversight, and land policies that promote climate change adaptation and mitigation for New Orleans and the wider regional ecosystem in "Climate Change and the Resilience of New Orleans." They make a series of recommendations regarding the restoration of ecosystem services and the potential benefits for urban systems.

Although we cannot accurately predict the specific long-term consequences of a changing climate for a particular city, we should embrace this uncertainty: It is important to move forward with the current state of knowledge and for cities to determine how best to mitigate GHG emissions in their own context—taking due care of national and international policies. Although uncertainty remains on the impacts of climate change, particularly at fine spatial scales, the research presented here and elsewhere demonstrates that new insights are being made available to others and are developing at a rapid pace. It is important for these to be translated into useful policy-making tools.

City Institutions and Governance for Climate Change

Shobhakar Dhakal and Enessa Janes

Appropriate forms of governance and institutional involvement are critical for achieving successful urban climate change mitigation and adaptation. The papers in this thematic area explore a unique aspect of governance and provide insights on current institutional considerations in the context of climate change. Together, they address a set of important questions, including the following:

- What are the motivations of cities to address climate change?
- What types of climate-related governance systems are currently being developed, and what are the institutional mechanisms that have emerged?
- What roles do nonstate and other stakeholders play in the governance process?
- What factors have enabled local institutions to become early adaptors of climate change mitigation and adaptation strategies?
- What are the major institutional barriers to successful climate change mitigation and adaptation in cities?
- How can we improve upon institutional capacity to enhance preparedness to the impacts of climatic change?

A number of important themes emerge from the discussion of urban climate change and governance. First is the analysis of factors that motivate cities to act and their willingness to make explicit commitments to build climate resilient cities. We have observed that the discourse on the urban impacts of climate change has been historically led by municipalities and municipal networks, associations, and organizations such as the Mayor's Climate Summit, ICLEI, C40 Cities, and the Climate Alliance. Recently other regional initiatives and multilateral organizations have joined the discussions.

The growing role of city governments in climate change can best be attributed to the following major factors: national mandates for cities to shoulder climate targets, lack of leadership on the part of some national governments, the willingness of some cities to participate on global issues without making serious commitments, expectations of new technology and funding related to climate initiatives, and new business prospects for local economies. Moreover, it is not uncommon for cities, often in developing countries, to make climate mitigation commitments without developing a clear idea of the ramifications for policy and implementation.

For these reasons, local knowledge, capacity, and governance are important for achieving successful adaptation and mitigation approaches. Carmin, Roberts, and Anguelovski show in the commissioned paper "Planning Climate Resilient Cities" that the enabling factors for early-adapter cities such as Durban and Quito are largely internal. These factors include local incentives, ideas, and knowledge generated through local demonstration projects and local networks, linking adaptation to ongoing programs, and the ability to enlist the support of diverse stakeholders from within the city. These dispel the prevalent notion that external factors are always the main drivers of action and help us to understand how a city's internal needs and priorities act as powerful agents for institutional responses to adaptation.

The second theme in the climate change and governance discussion has to do with the various forms of climate change governance, many of which are path dependent and reflect priorities and characteristics that are unique to each city. We observe that strong political leadership, very often by a mayor, is a key component to the development of appropriate city actions. This is especially true in cities in developing countries where international donors, local scholars, and civil society groups can help advance the climate agenda at a rapid pace. It is clear that the ability of local governments to gather resources and muster the legislative power needed to devise and enforce plans is a crucial factor for successful climate change governance. The commissioned paper "Cities and Climate Change: The Role of Institutions, Governance, and Planning for Mitigation and Adaptation by Cities" by Bulkeley and others points out that local governments can govern climate change mitigation in four ways: self-governing (reducing GHGs from municipal actions and activities), governing through legislation, governing by provisioning, and governing by enabling.

The rising interest of local governments in assuming more responsibility on the issue of climate change governance is a positive trend for cities around the globe. Nevertheless, policy debates often overemphasize the role of municipal governments and fail to take into account the limited ability of municipal governments in inducing substantial levels of emissions reductions. This limitation is due in part to structural factors in cities, such as the city's dominant role as a facilitator rather than an actor, the provisioning of municipal utility services by the private sector, and deteriorating financial performance.

Local governments, nongovernmental organizations, and other urban institutions (including state and national governments, scholarly communities, and local stakeholders) have their own impacts on fostering climate-resilient cities. Although the role of municipal government is absolutely necessary for implementing urban climate change mitigation and adaptation strategies, it is not the only responsible institution. It is evident that the most successful model for building urban climate resilience is a multilevel system of governance. Key issues associated with multilevel climate change governance include how to integrate a city's climate agenda into existing institutions (and vice versa), how to allocate responsibilities and actions across scales of governance in ways that allow capacity and resources to match policy influence, and how to foster collaboration and communication between various organizations and stakeholders. The paper by Bulkeley and others, mentioned above, as well as "Governance and Climate Change" by Gore, Robinson, and Stren and "Viral Governance and Mixed Motivations" by Warden, address these issues with several examples, the last two papers focusing on Canadian and U.S. cities.

A third theme is that of governmental policy frameworks and the positioning of policy instruments (economic, fiscal, regulatory, information and voluntary, and the like) into the prevailing socioeconomic and cultural contexts of cities. The ability to formulate sound, implementable policies and ensure effective, efficient results both relate to urban capacity and context. In "Adapting Cities to Climate Change," Heinrichs and others show us that early action requires strong leadership, risk awareness, interpersonal and interinstitutional interaction, dedicated climate teams, and enhanced financial capacity. In "Understanding and Improving Urban Responses to Climate Change," Sanchez Rodriguez emphasizes the role of urban planning in cultivating climate-resilient cities and questions whether planning institutions currently have the vision, capacity, and flexibility to guide future urban growth in resilient directions. He notes that collaboration among scientists, planners, policy makers, and urban stakeholders is paramount. Overall, the papers in this area have perhaps weakly addressed the issue of policy instruments and their implementation. However, several papers illustrate that institutional capacity, forms of governance, and other factors are fundamental to the success of policy instruments.

Current discussions about climate change mitigation and adaptation take place in a range of forums and involve different sets of stakeholders and institutions. Mitigation is often seen as a globally salient topic and is typically an intensely political issue. In contrast, adaptation is usually undertaken at the local scale and is less politically sensitive. Both strategies, however, should be integrated through the concept of urban resilience building. The shortcomings associated with planning separately for mitigation and adaptation include missed opportunities for developing efficient infrastructure and financially optimal climate solutions. Certainly there are no silver bullets for governance and institutional solutions. Every city is different, and each requires different sets of solutions suited to its social, economic, institutional, and cultural context. Ultimately, we should strive for an integrated approach to resilience, characterized by better coordination and coherent planning and governance.

Economic and Social Aspects of Climate Change and Cities

Chris Kennedy and Elliot Cohen

The papers in this area, discussing the social and economic dimensions of climate change, provide several key findings. In particular, the papers demonstrate the enormous social challenges faced by the urban poor in adapting to climate change and the inadequacy of current financing mechanisms to address these challenges. Some approaches to meet these financial demands are proposed, highlighting the specific roles of the private sector, community organizations, and local governments. Broader economic issues also are associated with climate change, such as potential changes to industry strategy and consumer preferences.

The uneven social impacts of climate change in urban areas and the distribution of risks among populations is stressed by Bartlett and others in their commissioned paper "Social Aspects of Climate Change in Urban Areas in Low- and Middle-Income Nations." Hundreds of millions of urban dwellers in low- and middle-income nations are at risk from current and likely future impacts of climate change. The risks, however, are distributed very unevenly because of differences in the magnitude and nature of hazards in different locations, the quality of housing, infrastructure, and services, measures taken for disaster risk reduction, the capacity and preparedness of local governments, and the social and political capital of vulnerable populations. The authors emphasize that vulnerabilities can be overcome by removing the hazards to which people are exposed, noting that measures taken to address climate change–related risks can be pro-poor, but many are anti-poor and increase poverty. They stress that pro-poor development has strong synergies with helping the poor adapt to climate change.

An asset-based framework for both understanding and operationally addressing the impacts of climate change on poor urban communities is presented by Moser in "A Conceptual and Operational Framework for Pro-Poor Asset Adaptation to Urban Climate Change." This framework has two components. First, the asset vulnerability of groups most affected by climate change–

related disasters is appraised for four interrelated phases: long-term resilience, pre-disaster damage limitation, immediate post-disaster response, and rebuilding. Second, bottom-up and top-down strategies for climate change adaptation that individuals, households, and communities have developed to cope with the four phases are identified.

In looking at the funding available for local governments to address mitigation and adaptation to climate change, Paulais and Pigey in their paper "Adaptation and Mitigation" find there is a "mismatch between needs and financing tools." Existing funding sources are found to be insufficient, highly fragmented, and generally not designed for local government use. They note that an integrated approach to investment in urban areas is required, and they are concerned that carbon finance through the Clean Development Mechanism in part may be substituting for, rather than adding to, traditional official development assistance. Moreover, though estimation is difficult, Paulais and Pigey suggest that the investment needs for mitigation and adaptation are one to two orders of magnitude greater than the funds available.

Several different approaches to meet the financial demands of climate change may be taken. To get more funding to local governments where it is needed, Paulais and Pigey consider cases with and without national intermediation agencies that can support or pool borrowers. To create more leverage and incentives for local governments, they suggest that climate change and pure development investment mechanisms be consolidated. They also suggest that incentives such as hybrid loans, credit enhancement, buy-down loans, and various tax incentives for the private sector be used. The authors also encourage a more prominent role for wealthy industrialized cities to partner with cities that are at low-income levels.

In contrast, Dodman, Mitlin, and Co in "Victims to Victors, Disasters to Opportunities" examine the potential for community-based initiatives to help the urban poor adapt to climate change. They draw upon the experiences of the Homeless People's Federation of the Philippines in responding to disasters. At the center of the organizing methodology are community savings programs, which provide a versatile means for acquisition of and relocation to less vulnerable areas, thereby enhancing disaster preparedness and risk reduction. The examples from the Philippines show how appropriate responses to some aspects of climate change can be implemented through partnerships among local organizations, professionals, and city officials.

The private sector has a substantial role to play in mobilizing resources to address climate change adaptation and mitigation. In "Mobilizing Private Sector Resources toward Climate Adaptation and Mitigation Action in Asia," Park explores this role, particularly in Asia. He suggests that increased investment could be achieved using institutional structure and public policy that can facilitate and create business-led innovation. Park also notes that it is challenging to ensure that climate solutions help, or at least do not harm, poor, energy insecure, and economically marginalized groups. He proposes a triple bottom-line strategy for financing climate change action in Asia. This involves the following: (1) investing in sector-based carbon mitigation strategy for industries, encouraged, for example, by reduction of fuel subsidies, (2) financing of community-based ecosystem and clean energy microenterprises, and (3) building resilience to climate change through market-based adaptation strategies, such as catastrophe bonds, contingent surplus notes, exchange-traded catastrophe options, catastrophe swaps, and weather derivatives.

Whether as part of market-based approaches to address climate change or otherwise, the cost of carbon is likely to rise, which will have substantial impacts on municipal finances. The paper by Annez and Zuelgaray, "High Cost Carbon and Local Government Finance," examines the financial impacts of rising carbon costs using case studies from the Indian state of Maharashtra and from Spain. They note that local government revenues are generally not dependent on the price of energy, and therefore local governments see negligible fiscal gain from increasing energy prices. On the other hand, many public services that local governments provide, such as garbage collection, are energy intensive. Consequently, higher energy prices will create an adverse fiscal shock for local governments. Hardest hit will be smaller, less diversified governments currently operating at low levels of service because the most basic services tend to be most energy intensive. Annez and Zuelgaray suggest that the appropriate policy response will be for higher levels of government, which generate surpluses from taxing energy, to compensate local governments hard hit by high energy bills. This is to protect the financial integrity of local governments and to ensure reasonable service delivery.

Climate change also has broader economic implications for, a few of which are addressed by other papers in this section. With respect to economic strategy, Zhang asks in her paper "Does Climate Change Make Industrialization an Obsolete Development Strategy for Cities in the South?" whether industrialization still represents a viable development strategy in the context of climate change. Through considering the development experiences of Shanghai, Mumbai, and Mexico City, Zhang argues that climate change makes industrialization an even more important strategy than before. Nonetheless, for the sake of local and national prosperity, as well as the global sustainability, it is critical that developing cities decarbonize their industries. Zhang suggests that the experience of Shanghai shows that this can be achieved. In "The Price of Climate," Cavailhès and others demonstrate economic benefits to climate change may be found, albeit in an industrialized country context. The authors use a hedonic price method to study consumer preferences in the face of climate change in France. Although very hot days are not desirable, the research shows that French households value warmer temperatures. Gross domestic product is calculated to rise by about 1 percent for a 1 degree Celsius rise in temperature.

The research findings presented above and discussed in the symposium demonstrate the interest of the research community and the rapid pace of production of new insights. At the same time, the symposium also revealed numerous areas where further work is required to strengthen diagnosis and policies. As mentioned in the introduction, the areas where most urgent research is required include adaptation in general, economic and social analysis broadly, and the specific needs and circumstances of developing country cities. Meanwhile, although there is considerable uncertainty on the specific long-term consequences of a changing climate in any particular city, it is important to move forward with the current state of knowledge. Cities need to determine how best to mitigate GHG emissions in their own context—in the context of national and international policies—and how best to respond and adapt to a changing climate. It is important for knowledge and research insights to be translated into useful policy-making tools, which we hope will follow from the 5th Urban Research Symposium.