Geographic Hotspots

For World Bank Action on Climate Change and Health

INVESTING IN CLIMATE CHANGE AND HEALTH SERIES

WORLD BANK GROUP

Geographic Hotspots for World Bank Action on Climate Change and Health

Investing in Climate Change and Health Series

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- "World Bank approach and action plan for climate change and health"
- "Geographic hotspots for World Bank action on climate change and health"
- "Climate-smart healthcare: low carbon and resilience strategies for the health sector"

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Foreword

Climate change is a risk multiplier that threatens to unravel decades of development gains. Among the most critical and direct risks to humans is the impact of climate change on health. Heat stress will worsen as high temperatures become more common and water scarcity increases; malnutrition, particularly in children, could become more prevalent in some parts of the world where droughts are expected to become more frequent; and water- and vector-borne diseases are likely to expand in range as conditions favor mosquitoes, flies, and water-borne pathogens. Worse still, these threats will be greatest in regions where the population is most dense, most vulnerable, and least equipped to adapt, pushing more people in poverty and reinforcing a cycle of environmental degradation, poor health and slow development.

Addressing these climate-associated health risks is critical. Alongside risk, there is opportunity. Responses to climate change have unearthed significant potential for improving both human health and the environment. Low carbon hospitals can draw upon the many advances made by the energy sector in developing cleaner and renewable resources. Pharmaceutical supply chains can benefit from more efficient and less polluting transport. And food and nutrition can be improved by the advances achieved through climate-smart agriculture.

Climate change challenges are multi-sectoral and so too are the solutions. At the World Bank Group, we are tackling different dimensions of these environment and health threats in different ways. For example, the 'Pollution Management and Environmental Health' Trust Fund addresses air pollution, toxic land pollution, and marine litter. Work on Climate-Smart Agriculture aims to sustainably increase food productivity and human well-being in a changing climate. We are putting in place a new operational framework for strengthening human, animal, and environmental health systems in response to disease threats. And within the health sector, we have made Universal Health Coverage core and increasingly considerate of climate change and resilience.

At the World Bank Group, we work with the broader development community to create solutions that can respond to and reduce these risks. Our work aligns with other global efforts aimed at improving environmental and human health, such as the work of the Climate and Clean Air Coalition, Global Alliance for Clean Cookstoves, One Health and Planetary Health communities, and broader efforts to achieve the Sustainable Development Goals.

Along with developing approaches and interventions, identifying geographic "hotspots" will help target resources to maximize impact and minimize risk. This report draws on the latest literature to highlight those regions and countries most likely to be adversely impacted and where action is most needed. While it is not a comprehensive resource for climate and health geography, the report creates entry points for discussions with country-level stakeholders.

The work presented here is expected to assist the development community in further mainstreaming climate change and health into development operations so that we may address the emerging needs of vulnerable communities, particularly women and children. We are committed to working with development practitioners around the world on climate change and health, capitalizing upon associated opportunities and technologies, and contributing to the overall goals of ending extreme poverty and boosting shared prosperity.

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Acronyms

AIDS	Acquired Immune Deficiency Syndrome
BEM	Building Energy Management
BREEAM	British Research Establishment Ltd—Environmental Assessment Method
CCSA	Cross-cutting solutions area
CFL	Compact Fluorescent Lightbulb
CO_2	Carbon Dioxide
CO_2e	Carbon Dioside equivalent
EDGE	Excellence in Design for Greater Efficiencies
GAVI	Global Alliance for Vaccines and Immunizations
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GP	Global Practice
HCWH	Healthcare Without Harm
HFC	Hydrofluorocarbon
HIV	Human Immunodeficiency Virus
HNP	Health Nutrition and Population (World Bank Global Practice)
HVAC	Heating, Ventilation, & Air Conditioning
IPCC	Intergovernmental Panel on Climate Change
kBTU/sf/yr	Kilo (x1000) British Thermal Unit per Square Foot per Year
LED	Light Emitting Diode
LEED	Leadership in Energy & Environmental Design
MAC	Marginal Abatement Curve
MATCCH	Mobilizing Action Toward Climate Change and Health
MDR-TB	Multi Drug Resistant Tuberculosis
NDGAIN	Notre Dame Global Adaptation Initiative
NHS	National Health Service (UK)
N_2O	Nitrous Oxide
PAHO	Pan American Health Organization
QALY	Quality Adjusted Life Year
SE4All	Sustainable Energy for All
SDG	Sustainable Development Goal
SMART	Specific, Measurable, Achieveable, Relevant, Time-bound
tCO_2	Tons of Carbon Dioxide
UNEP	United Nations Environment Program
UNFPA	United Nations Population Fund (previously UN Fund for Population Activities)
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children's Emergency Fund
UNITAID	Not an acronym, this is a global health initiative, hosted by WHO to tackle deficiencies in management of HIV/AIDS, Tuberculosis and Malaria
UNOPS	United Nations Office for Project Services
USAID	United States Agency for international Development
WHO	World Health Organization

Executive Summary

Climate change and the pollutants associated with it[1] have impacts across many dimensions of life. Importantly this includes the health of those who are living in areas most vulnerable to its effects and who are subject to the various forms of air pollution that help drive climate change in the first place. Accordingly, countries should be encouraged to place health improvements at the core of their efforts to address climate change and its drivers, based on the best estimates of how they or their regions are being impacted now and will be in the years ahead.

Without proactive, integrated planning, the impacts of climate change will fall disproportionately on the poorest people worldwide, further hampering efforts to alleviate poverty, provide universal health coverage, and ensure shared prosperity. Climate impacts on population's health can be direct (heat waves, floods), or mediated through natural systems (air quality, water and vectors), or socioeconomic systems (food production, health care, poverty). Naturally, climate change and the drivers behind it affect countries differently, and each country will also differ in terms of its readiness and capacity to cope with these developments and implications for national health. The question that has become more pressing is which countries are most vulnerable to climate change and its drivers from a health perspective and what they could do to mitigate or adapt in the face of this challenge.

This report addresses this need by examining the latest climate change research and evaluating the strength of national health systems worldwide to provide a guide to those countries that would most benefit from immediate efforts to ensure that health considerations are at the forefront of climate change adaptation responses and mitigation measures. We have drawn upon recognized vulnerability indices related to health outcomes, data outlining the disease burden linked to pollution, and proxies that measure country health systems' performance or readiness to cope with increased burden of disease.

The objective is not to rank countries, but rather to provide a ready guide to those most vulnerable. The World Bank Group and others can then prioritize their efforts to help countries mitigate the drivers of climate change (thereby alleviating the associated health impacts of air pollution) or adapt to the impacts of climate change in their respective development policies and programs. It is important to recognize that climate change and the emissions that promote it are not limited by national borders or regional boundaries. However, the World Bank and others work with national governments to help them adapt and mitigate impacts, requiring data provision and analysis on a country basis. It should also be noted that threats can vary within countries, and indeed climate change and emissions might well not even rank among a country's most significant sources of death and disease in the face of other health threats.

As such, this work will inform the World Bank's approach to health-related aspects of climate change across its work with countries, including through a proposed 5-year action plan to integrate

1 Climate drivers that affect health outcomes include fine particulate matter (including black carbon which is a strong warming agent and other components of aerosol particulate that may offset a portion of that warming) and methane, which contributes to the formation of ground-level ozone or smog.

health-related climate considerations in its strategies and investments. The Bank will be able to bring its combined strengths in analysis and operations to those countries seeking an integrated approach to reduce the health impacts of climate change and its drivers that encompasses health, transport, energy, agriculture, environmental management and economic sectors.

Climate Change, Its Drivers, and Their Impacts on Health

There is mounting evidence that climate change is and will continue to negatively impact health in many countries. Rising temperatures bring heat stress and encourage the spread of vector-borne diseases. A rising number of more extreme weather events—such as storms and torrential rains—cause death and injuries, foster water-borne diseases, and destroy crops, greatly increasing food insecurity and the risk of undernutrition. The emissions that contribute to climate change are already degrading air quality, causing respiratory and cardiac problems and certain cancers, killing more than 5.5 million people each year.

Highly conservative estimates from WHO suggest that, compared to projections without climate change for the years between 2030 and 2050, more than 38,000 additional people are expected to die of heat exposure, 48,000 due to diarrhea, 60,000 from malaria, and 95,000 from childhood undernutrition, a total of 251,000 deaths each year for only three diseases. Analysis suggests that the added costs of coping with malaria, diarrheal illnesses, and malnutrition alone could cost between US$4–12 billion per year. Natural disasters from weather-related causes pose additional costs. Data for developing countries are sparse but climate-related disasters in the US likely cost around US$14 billion over a single 10-year period.

Identifying the Countries Most at Risk for Climate Change Impacts on Health

Climate-sensitive health impacts can be traced to certain geographies: tropical and equatorial areas are more sensitive to heat increases as are cities, as these magnify heat impacts. Accordingly, parts of South Asia are seen to be most at risk in this regard, as are parts of Sub-Saharan Africa, particularly inland populations with already scarce water supplies. People living on flood plains, small catchments, or on coastlines are also at risk from floods and storms and can include those living in Asia, Africa, small island states, and Central and South America.

Regions at risk for vector-borne diseases associated with climate shifts include Africa and Southeast Asia (malaria), Asia-Pacific (dengue), temperate parts of Europe, Asia, and North America (Lyme disease), and Russia, Mongolia, and China (encephalitis). Southeast Asia is also at risk for climate change-influenced food- and waterborne diseases while this region and Sub-Saharan Africa, East Asia, and the Pacific are vulnerable to food supply problems associated with climate change.

Judging which individual countries might be at greatest risk from climate change-related health problems is complicated by the fact that many key factors do not map neatly to country borders; e.g., rising seas or heat impacts. However, the World Bank has used the "ND-GAIN" country index to best assess the risks, as it takes into account a country's vulnerability across a number of measures that are updated regularly, including ecosystem services, food, health, human habitats, infrastructure, and water.

By combining a number of the ND-GAIN measures to judge a country's vulnerability to health impacts as well as its relative readiness to cope with such problems, a picture emerges of those countries that should prioritize their efforts to adapt or mitigate these impacts, possibly with help from the World Bank or others. The group of hotspots that emerges as being most at risk from both direct exposure to climate change as well as its effects on disease includes several Africa nations (including Benin, Burkina Faso, Burundi, Central African Republic, Chad, Congo, Democratic Republic of Congo, Djibouti, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Niger, Rwanda, Sao Tome and Principe, Sierra Leone, Somalia, Togo, and Zambia), a few in the Pacific (Micronesia, Papua New Guinea, Solomon Islands, Timor-Leste, and Vanuatu), and Yemen in the Middle East. Many others are particularly vulnerable from either direct exposure or disease impact from climate change, but not both.

Broadening the Analysis to Include "Emissions" Hotspots

Countries most at risk can be viewed as either climate "impact" hotspots, which are those most likely to experience a significant change in the climate-sensitive burden of disease, and climate "emissions" hotspots, which refers to those most vulnerable to emission-sensitive disease associated with exposure to air pollution co-emitted with key drivers of climate change (i.e., greenhouse gases or GHGs and short-lived climate pollutants). Those countries listed above are climate-sensitive "impact" hotspots.

"Emission" hotspots that are already experiencing a high burden of disease from ambient air pollution (as opposed to household air pollution, produced by residential cooking or heating) include Azerbaijan, China, Mauritania, Tajikistan, Turkmenistan, and Uzbekistan. Hotspots for household air pollution include Haiti, Laos, Nepal, Papua New Guinea, Philippines, Solomon Islands, Sri Lanka, Timor Leste, Vanuatu and 22 countries in Sub-Saharan Africa. Afghanistan, Bangladesh, Cambodia, India, Myanmar and North Korea suffer from both.

Nearly all of these hotspot countries are estimated to have challenges with their health system readiness to address the health impacts from air pollution.

Adaptation and Mitigation Efforts Can Save Millions of Lives

Positive change is possible. It has long been understood that steps can be taken to reduce the impacts of climate change in many fields, including health outcomes. Most of the identified hotspots are poorer nations, often insufficiently prepared to reduce their vulnerability through proper adaptation and emission reduction (climate mitigation) measures. As such, the World Bank can play a significant role—both through financial and technical assistance—in helping countries take steps to adapt to or mitigate climate change impacts on the health of their people.

On the adaptation side, better preparedness in Bangladesh, for example, has helped reduce the casualties from cyclones and severe storms in recent decades. To fight the threat posed by malaria during lengthening wet seasons, countries could extend their insecticide spraying efforts or broaden their reach to match the expansion of breeding areas fostered by climate change. Approaches will need to be tailored to each country's circumstances, geography, and preparedness, but the World Bank is emphasizing a "climate-smart" strategy that aims to improve on the one hand the health system, and on the other those systems that mediate a good part of the heath impact of climate change such as access to energy and clean water, and urban development.

Emission reduction strategies likely represent the most effective mitigation steps that would benefit both the climate and health conditions in vulnerable countries. By some estimates, more than 2.4 million lives could be saved each year from 2030 by reducing emissions of short-lived climate pollutants, such as black carbon and methane.

Climate change, its drivers, and its impacts are issues that require solutions beyond a single sector, location, country or region and as such the World Bank can play a significant part in helping countries confront these challenges. The Bank not only has the financial and technical resources to provide direct assistance, it can also bring together those players with additional expertise to help a country strengthen its planning and response to climate-related health impacts. This paper represents an effort to identify those countries and regions that should be viewed as priority hotspots by the Bank and its allies as it seeks to target its support.

Introduction

In the last 5 years, the number of voices calling for stronger international action on climate change and health has increased,[2] as has the scale and depth of activities. But current global efforts in climate and health are inadequately integrated. As a result, actions to address climate change—including World Bank Group investment and lending—are missing opportunities to simultaneously promote better health outcomes and resilience.

Accordingly, the World Bank Group has developed a 4-year action plan and new approaches to integrate health-related climate considerations into World Bank sector plans and investments. This "Approach and Action Plan" seeks to stimulate and support greater attention to both the health dimensions of climate-smart investments across sectors and to climate risk in health sector knowledge products and operations.

An initial step—presented here—is the use of existing indicators to identify countries where climate change, or exposure to drivers of climate change (i.e., kinds of air pollution), are expected to most significantly alter the burden of disease and expose vulnerabilities in existing health systems. While not based on primary analysis, this paper will serve as an initial filter, focusing the approach on specific countries or "hotspots" where World Bank operations can maximize positive health outcomes in the face of climate change and its drivers, and to prioritize the approach on the basis of vulnerability and exposure. The analysis presented in this work will ultimately be combined with sector analyses in additional analytic work to further specify approaches to climate-health action.

This paper begins by identifying the health impacts that are being felt today and that are projected to worsen in the future without efforts to ensure health considerations are central to any and all climate change adaptation and mitigation measures. Chapter 1 includes an outline of the scope of health impacts from climate change and its drivers, the means of transmission, and a description of the drivers of climate change, and their sources.

What is needed to ensure that health is put at the forefront of climate change action is a guide to those countries most vulnerable to increasing numbers of deaths and greater illness from climate change, and co-pollutants from GHG sources, referred to here as climate drivers. Chapter 2 describes the methodology used to identify these nations and determine their preparedness for coping with these impacts. Chapter 3 identifies hotspot countries based on this analysis, and narrows the focus to those countries that are both most likely to bear the brunt of a greater burden of disease and death from climate change and climate drivers, and that are the least ready to cope.

Coping mechanisms—through mitigation and adaptation measures—are outlined in Chapter 4, as are the multiple benefits that can be expected from multi-sector, concerted efforts to address health impacts from climate change, and its drivers.

2 Climate change has been called both the 'biggest global health threat' and the 'greatest global health opportunity" of the 21st century (Costello, 2009; Watts, 2015). The Director General of the World Health Organization (WHO) has called climate change "the defining global health threat of the 21st century," and the Executive Secretary of the United Nations Framework Convention on Climate Change has noted "a climate agreement is a global health agreement."

CHAPTER

1

Health Impacts Due to Climate Change and Its Drivers

The Scale and Scope of Health Impacts Due to Climate Change and Climate Drivers

Climate change complicates the search for solutions to almost all development challenges and threatens to erase the many development gains of the past several decades. There is clear and mounting evidence that health outcomes will—in large part—be negatively impacted by climate change. Heat stress is seen increasing with higher temperatures. A growing number of climate-related extreme events such as floods and torrential rains could increase the incidence of waterborne diseases and affect crops, increase food insecurity and, potentially, undernutrition. Rising sea levels affect populations of entire islands and coastal areas. Rising average temperatures can open new areas to the transmission of certain vector-borne diseases (i.e., those transmitted by carriers such as insects). These effects are detailed below. The emissions that drive climate change are also associated with various public health threats through air quality impacts that are linked to respiratory and cardiac threats, as well as certain cancers.

These impacts will be greatest in the poorest countries and regions where the populations are most dense, most vulnerable, and least equipped to adapt. Here, health and malnutrition hold the potential for broad intergenerational impacts; a whole generation of youth risks becoming disenfranchised and held back in school (World Bank, 2014). Moreover, in general, poor and disenfranchised groups, women, elderly and children, are most at risk (Smith et al., 2014; World Bank, 2012, 2013).

Given the complexity of social and environmental factors that influence disease and health outcomes, the precise extent of these impacts is difficult to establish, though estimates from the most informed health sources expect climate change will increase the incidence of several diseases. The World Health Organization (WHO), for example, estimated in the early 2000s that climate change was already accounting for an additional 150,000 deaths a year (WHO, 2004). Updated data suggest that, compared to a future without climate change (for the year 2030), an additional 38,000 deaths are expected due to heat exposure in elderly people, 48,000 due to diarrhea, 60,000 due to malaria, and 95,000 due to childhood undernutrition[3] (WHO, 2014b). This will correspond to an additional 250,000 deaths per year from heat exposure, undernutrition, malaria, and diarrheal disease due to climate change each year from 2030 through 2050. This estimate is low, however, because it does not include all climate-sensitive health impacts, such as pollution, injuries, non-malarial infectious diseases, and others for which projection data are lacking (WHO, 2014b).

This additional burden of disease comes with significant economic impacts. One study estimated additional costs associated with climate-change related cases of just three sets of diseases (malaria, diarrheal illnesses, and malnutrition) to be between US$4–12 billion in 2030 under a 750 parts per

3 Following this period, there is a projected decline in child mortality from malnutrition and diarrheal disease between 2030 and 2050. Conversely, over the same period, deaths related to heat exposure (over 100,000 per year) are projected to increase.

Table 1.1: Projected excess costs (US$, millions) to manage climate change-related cases of select climate-sensitive diseases for two scenarios relative to baseline.

SCENARIO	DIARRHEAL DISEASES		MALNUTRITION		MALARIA	
	MID	HIGH	MID	HIGH	MID	HIGH
S550	1,706	6,024	53.9–71.5	112.9–149.9	1,573–2,145	3,236–4,515
S750	1,983	6,814	81.3–107.9	162.5–215.6	1,928–2,691	3,994–5,573
UE	2,731	9,010	62.2–82.6	125.2–166.2	3,059–4,269	6,293–8,781

Source: Ebi, 2008.

million (ppm; business as usual) scenario. Costs increase with greater climate change as illustrated in Table 1.1 (Ebi, 2008). Separate work suggests there are significant costs associated with disaster-related health impacts as well. Though little data has been produced on this topic for the developing world, it was estimated that climate-related disasters have already caused US$14 billion in health-related costs over a 10-year period in the US alone (Knowlton, 2011). Other research has estimated that impacts associated with labor productivity losses due to excess heat (correlating to health stress) might be as much as 11–20 percent by 2080 in heat-prone regions like Asia and the Caribbean. This results in billions of dollars in associated impacts from labor losses and direct health impacts (Kjellstrom, 2009). Avoiding these health impacts (and limiting global warming to 2°C) can yield economic savings that exceed the US$1.5–2 billion per year outlaid for health sector adaptation and can begin to approach the estimated US$70–100 billion per year of overall adaptation investment needed by 2050 (World Bank, 2010).

Importantly, not all climate-related health impacts of concern will occur in the future. Along with some direct impacts, the emissions that drive climate change are largely co-emitted by the same sources that are responsible for air pollution. WHO has recognized the large and significant role that ambient air pollution (AAP) and, in the developing world, household air pollution (HAP) play in increasing morbidity and mortality around the globe (WHO, 2014a). The most recent Global Burden of Disease estimates suggest that AAP and HAP combined were killing more than 5.5 million people annually by 2013 (GBD 2013 Risk Factors Collaborators, 2015). Of the 5.5 million total premature deaths per year—more deaths than those attributable to malaria or tuberculosis—2.9 million are due to exposure to household smoke from cooking, which constitutes the fourth ranked risk factor for disease in developing countries (WHO, 2014a) and is a major source of black carbon, a short-lived but powerful driver of a warmer atmosphere. Tens of millions more suffer from related, preventable diseases, including pneumonia (which predominantly affects children), lung cancer, cardiovascular disease, stroke, and chronic obstructive pulmonary disease, which includes emphysema and bronchitis (WHO, 2014a).

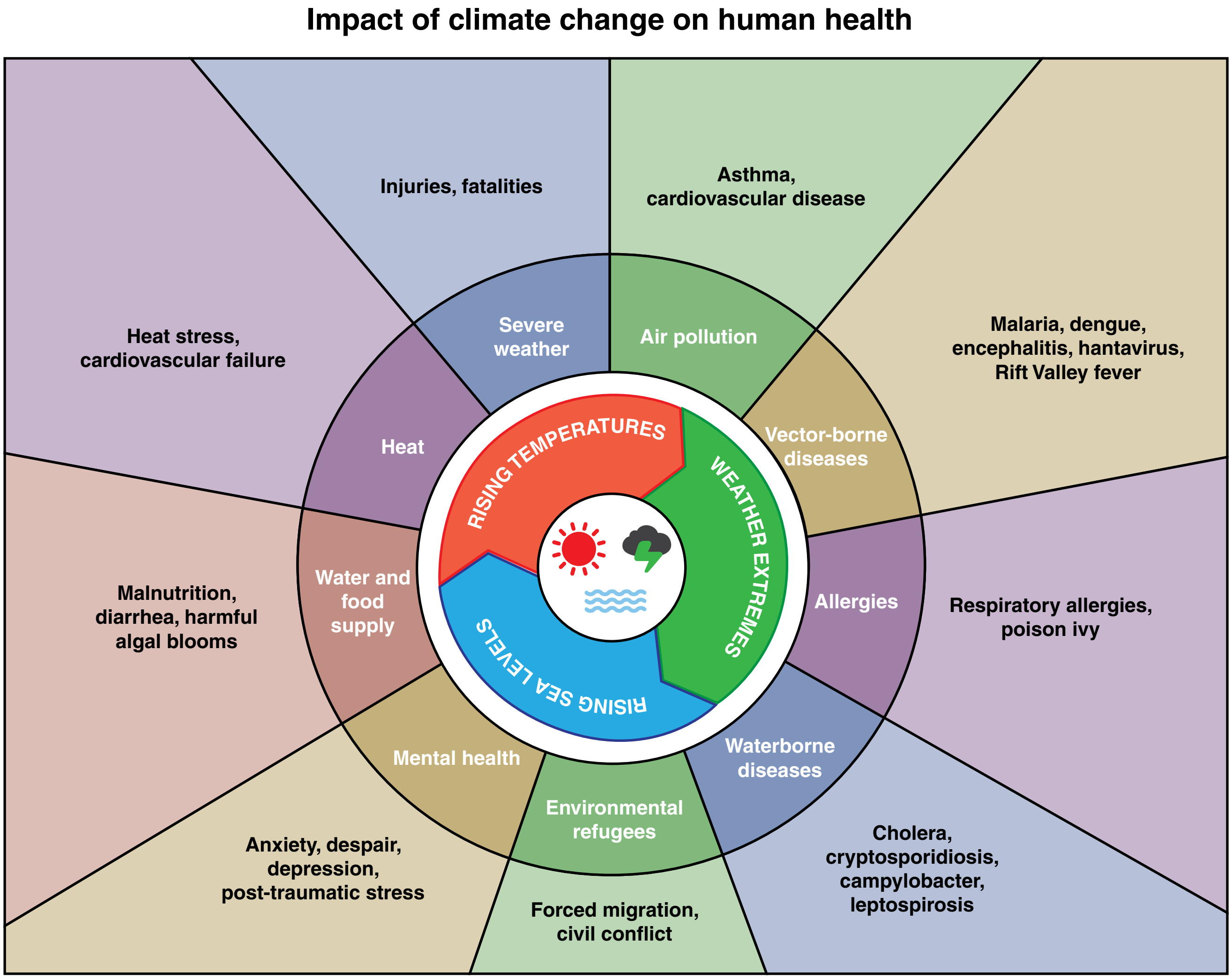
There is a significant economic cost associated with the air pollution-related burden of disease. A recent study by WHO and the Organization for Economic Co-operation and Development (OECD, 2015) estimated that in Europe alone, 600,000 annual premature air pollution-related deaths cost US$1.6 trillion. Separately, OECD (2014) found that air pollution morbidities and mortalities correspond to US$1.7 trillion in costs annually in OECD countries, US$1.4 trillion in China, and US$500 billion in India. A significant portion of these deaths can be avoided with stringent climate mitigation, given air pollution's role as a co-emitted by-product of fossil-fuel combustion. The remaining deaths could also be averted through mitigation of black carbon and methane, the so-called short-lived climate pollutants or SLCPs (Rogelj et al., 2014).

How Climate and Climate Drivers Affect Health Outcomes

Figure 1.1 shows the spectrum of climate-sensitive health impacts and correlates them to environmental variables, sensitive to a cycle of broader climatic change. Such a framework can be useful for quantifying health impacts, identifying disease-specific or environmental interventions, or for interacting with health specialists (and others) comfortable with health impacts and outcomes. To meet the overarching goal of the World Bank Climate and Health Approach Paper, a framework is needed that will go beyond merely identifying health impacts to address the development of solutions. At the same time, it is essential to create a framework that identifies the pathways by which climate change results in health impacts.

In March 2014, the Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report, including a chapter on health and climate change (Smith et al., 2014). The authors describe three pathways through which climate impacts health: 1) a direct exposure; 2) indirect exposure, in which health impacts are mediated through environmental and ecosystem changes; and 3) another indirect pathway mediated through societal systems (e.g., food and water distribution systems).

Figure 1.1: The ways climate change can affect health; all are preventable.

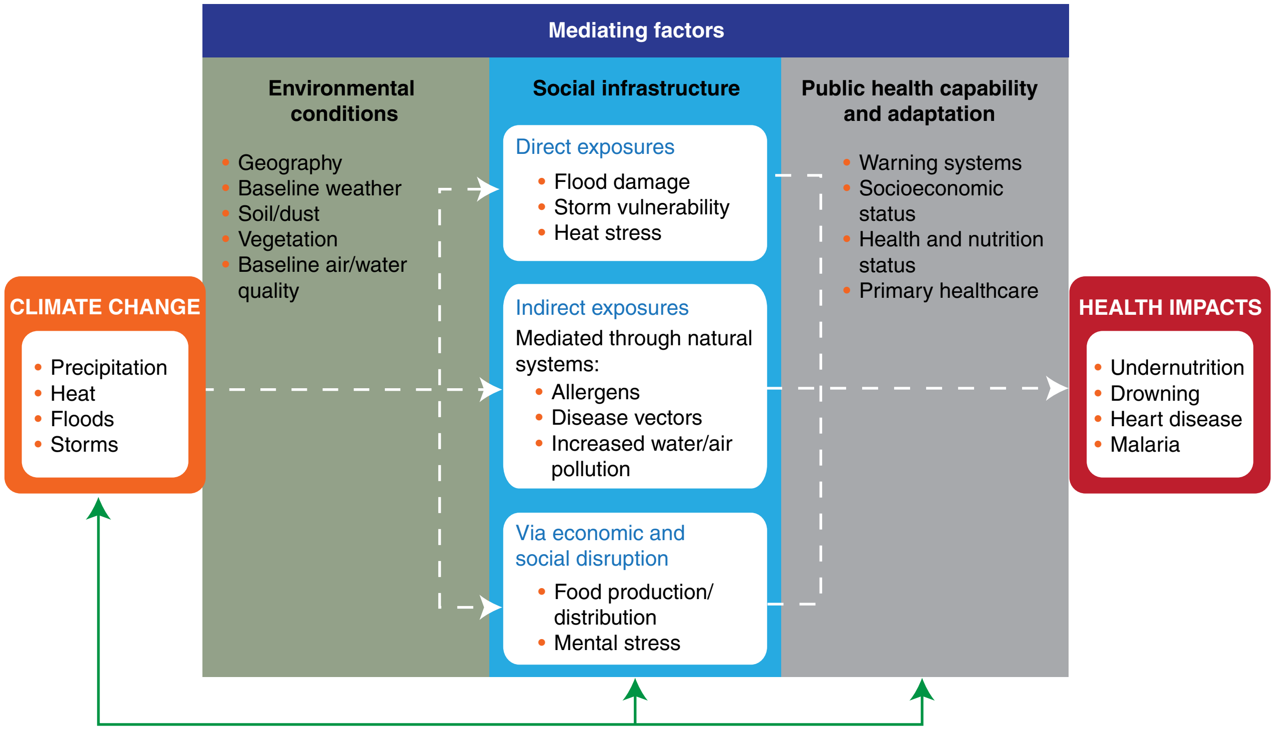


Source: Adapted from J. Patz. National Oceanic and Atmospheric Administration (https://toolkit.climate.gov/image/505).

In Figure 1.2, the green box indicates the moderating influences of local environmental conditions on climate change exposure pathways in a particular population. The gray box indicates the extent to which factors as background public health and socioeconomic conditions, and adaptation measures moderate the actual health burden produced by the three categories of exposure. The green arrows at the bottom indicate that there may be feedback mechanisms—positive or negative—between societal infrastructure, public health, and adaptation measures and climate change itself (Smith et al., 2014). While this provides a framework for considering the exposure pathways of climate impacts on health, it does not adequately address the health impacts of exposure to the *drivers* of climate change and co-emitted air pollution. Figure 1.3 provides a more comprehensive picture in that it includes pathways through which health-relevant drivers of climate change are also determinants of health and health outcomes.

The health impacts from emissions are underway now and, barring change, they will increase in the coming years as the exposure pathways of climate change add to the current exposure to air pollution. Ultimately, the overall impact will depend on emissions scenarios, population growth, and other biophysical and socially mediated factors.

Figure 1.2: Exposure pathways by which climate change affects health.



Source: Smith et al., 2014.

Despite its narrower consideration of only one aspect of air pollution's impact on health,[4] we adopt the three-pathway IPCC model (over a more health-centric approach, as illustrated in Figure 1.1) to classify various health impacts of climate change for this analysis. In doing so, we acknowledge the importance of understanding discrete health endpoints, but opt for a classification that highlights the linkage between environmental drivers of disease and vulnerability and indices that point toward approaches to adaptation and mitigation. In addition, we classify climate drivers by source type and their impact on health as recognized by the World Health Organization.

The IPCC classification (Smith et al., 2014) includes: the direct pathway of climate change impact on health; an ecosystem-mediated pathway for health impacts; and a human-institution mediated pathway for health impacts. Co-emitted air pollution is treated separately to better account for the health impacts associated with the drivers of climate change and is classified in terms of sources that contribute to ambient air pollution versus those that contribute to household air pollution.

Direct Pathway to Health Impacts

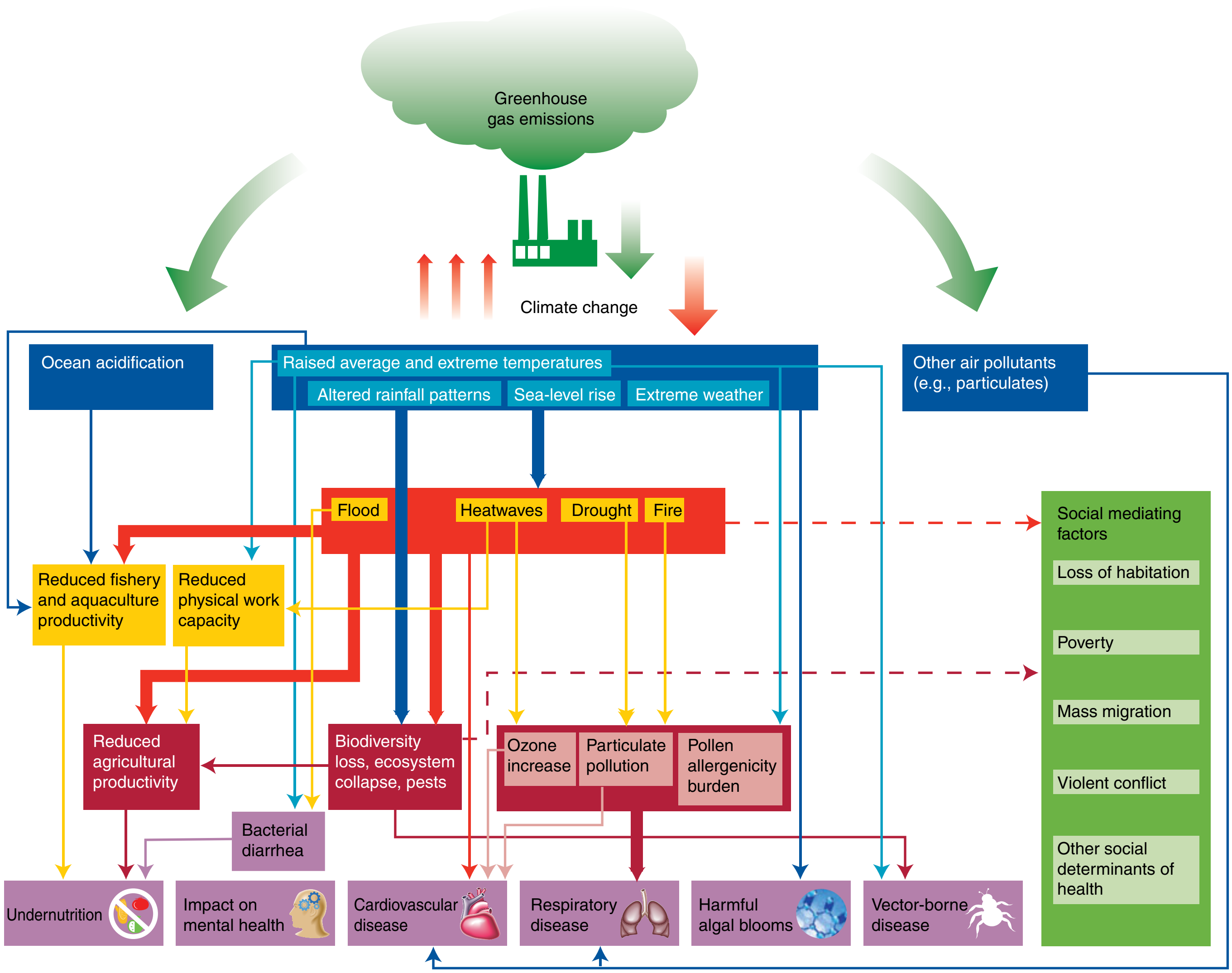
This pathway refers to direct illness and death due to exposure to extreme weather events in which climate change may play a role. These include effects of high heat (including "heat exhaustion" and heat waves), floods, storms, etc.

Heat and Cold-Related Impacts

The association between hot days and mortality is well-defined. IPCC has concluded that it is *very likely* there has been a greater number of hot days and nights on account of climate change, likely correlating to mortality from heat waves. This rise in temperatures means, however, that minimum temperatures have increased, potentially lowering winter mortality rates. While this may be the case, research suggests that the detriments of heat extremes outweigh the benefits of fewer cold days (Smith et al., 2014).

4 Changes in air quality due to warmer temperatures and changing meteorological patterns are addressed by the IPCC framework. The framework does not direct air quality health impact from pollution that is co-emitted with the drivers of climate change; i.e., both greenhouse gases and short-lived climate pollutants.

Figure 1.3: Links between greenhouse gas emissions, climate change and health.



Source: Watts, 2015.

Floods and Storms

These are particularly important events, given they are the most frequent types of natural disaster, with significant correlation to climate fluctuations. Floods and storms can lead to many socially-mediated health impacts following disaster events: malnutrition, disease, and mental illness. However, available data usually refer to direct health impacts, typically only injuries and mortality (Smith et al., 2014).

Ecosystem-Mediated Pathway

This applies to illnesses and deaths due to such as shifts in patterns of disease-carrying mosquitoes and ticks, or increases in waterborne diseases caused by warmer conditions and increased precipitation and runoff.

Vector-Borne Diseases

These diseases, transmitted by biting or blood-sucking insects, are among the most closely studied in relation to climate change, given their known sensitivity to weather and climatic factors. Malaria and dengue fever are perhaps the two most significant diseases, with nearly 300 million cases combined each year (WHO, 2009). There are also many tens of thousands of cases annually of Lyme disease, tick-borne encephalitis, hemorrhagic fever, and others. The sensitivities of these diseases to specific climatic variables (temperature, precipitation, humidity) is nonlinear and variable by species and transmitted disease. Nevertheless, confidence levels are high that the incidence of many of these diseases will increase as the climate changes, particularly in their endemic regions (Smith et al., 2014).

Food and Waterborne Infections

Humans are exposed to these pathogens by ingesting contaminated water or food or through contact while swimming, bathing, or other environmental contact with orifices or open wounds. Climate may affect the growth of these organisms, resulting in higher environmental concentrations and increasing likelihood that they will infect humans. Examples include *Vibrio cholerae,* salmonella, campylobacter, and harmful algal blooms. Most infection rates are associated with higher temperatures and precipitation, which can cause agricultural runoff leading to water contamination (Smith et al., 2014). Many studies project an increased correlation of diarrheal diseases at regional and country levels in a future with greater climate change.

Air Quality

Acute air pollution episodes from wildfires and aeroallergens are projected to worsen with warmer temperatures and will have an effect on asthma and allergic respiratory diseases (Beggs, 2010). We address the health effects of air pollution through a separate exposure pathway shortly in this chapter.

Pathway Mediated through Societal Systems and Human Institutions

This includes death and sickness from altered systems created by humans. These include agricultural production and distribution, urban environments and food insecurity, stress and undernutrition and violent conflict caused by population displacement, economic losses due to widespread "heat exhaustion" impacts on the workforce, or other environmental stressors.

Undernutrition

Food, being a function of agriculture, is both closely connected to climate change and to socioeconomic factors that influence production. From the extensive modeling of climate impacts on agriculture, it is clear that many regions are susceptible to food system impacts (Smith et al., 2014).

Drivers of Climate Change and Their Sources

Air pollution is a risk factor for several causes of death and is the leading environmental contributor to the global burden of disease. Cardiovascular and cerebrovascular causes of death account for the greater share of attributable mortality: 80 percent in the case of ambient air pollution and 60 percent in the case of household air pollution, followed by chronic obstructive pulmonary disease, lung cancers and pneumonia (WHO, 2014c). The concept of air pollution and its importance for development is not new and the World Bank's Environment Global Practice has a strong history of engagement with client countries on improving air quality, as outlined in Box 1.1.

Changes in climate can also result in incremental changes in air quality through, for example, increased stagnation, warmer temperatures, increased humidity and other meteorological factors that control the secondary formation of ground-level ozone and fine particle matter (Jacob & Winner, 2009). However, emissions constitute a far greater determinant of both ambient and

Box 1.1: The World Bank and Air Quality Initiatives around the World

Colombia. Analytical work conducted by the World Bank in Colombia included a study of the costs of environmental degradation, which estimated that outdoor air pollution was responsible for approximately 6,000 premature deaths a year, equal to a cost of approximately 0.8 percent of GDP. This work highlighted the need for revising air quality standards and resulted in a broad public debate, which was taken up by politicians and led to development of a more stringent Fuel Quality Law after 13 failed attempts at revision over the course of a decade.

Mongolia. Due to famines and hunger among nomads throughout the vast lands of the Mongolian steppe, extensive immigration is occurring into the Ger areas around Mongolia's capital, Ulaanbaatar, almost tripling its population. It is estimated there have been 1,600 premature deaths a year in Ulaanbaatar, largely attributable fine particle pollution from low-efficiency, high-polluting heaters and stoves in these areas; particle concentrations in the city have been up to 35 times WHO-recommended standards. The World Bank undertook a comprehensive air quality management study for Ulaanbaatar that has led to a program that replaces ovens in all 170,000 Ger households. This, combined with other abatement initiatives, has resulted in the gradual return of clean, clear air with fewer reports of deaths and illness.

China. In China, the World Bank—in cooperation with the Ministry of Environmental Protection—prepared a report designing a national program to reduce two types of airborne pollution (known as PM_{10} and $PM_{2.5}$) in all 655 cities. In 2012, China's State Council authorized new air quality regulations aiming for a 30 percent reduction in PM_{10} and establishing new standards for $PM_{2.5}$. New standards went into effect on January 1, 2016 and each of the 655 cities in China are now preparing plans for how to achieve these targets on a staggered time schedule.

household air pollution levels relative to climate change impacts on meteorological factors. While the health sector is not the largest source of air pollution or associated drivers of climate change, it can take steps to address its share of these emissions as noted in Box 1.2 below.

Pollutants versus Sources

When assessing linkages to public health, one must consider co-emitted pollutants in addition to greenhouse gases and short-lived climate pollutants (SLCPs), the principal drivers of long-term and near-term climate change, respectively. These emissions must be assessed in the context of the comprehensive effects of all species emitted by a given source. Some sources drive climate change (e.g., emitters of greenhouse gases or hydrofluorocarbons alone) and have no apparent health impact at all, but these are extremely rare; most sources of climate or air pollution emit a variety of pollutants in a combined exhaust mixture (see Box 1.3). In addition, some sources are natural in origin (e.g., sea salt aerosol) or are associated with non-combustion related human activities, such as mineral dust from unpaved roads or agricultural activities. There is less scope for World Bank initiatives in addressing these pollution sources and as such they are not the focus of this work.

While each pollutant may be responsible for various environmental or public health concerns, the source of emissions—whether it is a power plant, a car or a cookstove—may contribute to one or more categories of impact (i.e., health, climate, agriculture, etc.). Significant overlap exists between sources whose emissions drive climate change and those with significant health impact via fine particle and ozone pollution.

Box 1.2: The Health Sector as a Climate Driver

To meet its primary obligation to do no harm, the health sector has a responsibility to put its own house in order so that its practices, the products it consumes, and the buildings it operates do not harm human health and the environment. In this way, the health sector can play a leadership role in mitigating climate change by reducing the energy- and resource-intensity of health care provision. This will significantly reduce emissions that drive climate change, along with the attendant health consequences associated with climate vulnerability and respiratory and other illness associated with air pollution.

Actions include health system designs that embrace energy efficiency, green building design, alternative energy generation, 'green' transportation for staff and patients, sustainable and local food provision, integrated solid waste management and water conservation measures.

In addition to a focus on the built environment and the provision of services, there are a range of possible initiatives for multilateral aid agencies and international institutions, ministries of health, health care agencies and health providers. Everyone has a role to play in minimizing the climate footprint of the health sector by ensuring adequate finance for change, embracing an economic system that promotes health, social justice, and survival for current and future generations, and raising awareness of current and projected adverse and inequitable health impacts of climate change (including health co-benefits of mitigation).

These specific actions are the focus of a new World Bank report: "Climate Smart Healthcare: Low Carbon & Resilience Strategies for the Health Sector."

Source: *Healthy Hospitals, Healthy Planet, Healthy People: Addressing climate change in health care settings,* WHO/Health Care Without Harm (2008).

Box 1.3: Examples of Sources with Multiple Pollutants and Multiple Effects

For those health impacts that flow directly from air emissions, it is important to distinguish the pollutants from their sources. For example, diesel engines are among the largest sources of black carbon, a powerful short-lived climate pollutant, but they also emit carbon dioxide (CO_2), nitrogen oxides (NO_X), volatile organic compounds (VOC), air toxins and other components of air pollution with public health consequences. Through this panoply of pollutants, diesel engines have a clear impact on long-term climate instability (from CO_2 emissions), near-term warming (black carbon) and are a ubiquitous source of ambient air pollution through black carbon's contribution to primary fine particulate matter ($PM_{2.5}$) and the additional emission of NO_X and VOC, which contribute to formation of ground-level ozone (smog) and secondary $PM_{2.5}$.

Assessing the impacts from the use of solid biomass fuels—used for residential energy in many parts of the world—is even more complex. The damage to public health is undeniable with residential biomass combustion contributing strongly to household air pollution and more than 4.3 million premature deaths each year in 2010 (Lim et al., 2012). Its influence on climate, however, depends on a number of factors including combustion conditions, the location of emissions and the source of biomass. Residential biomass combustion is a large source of black carbon, co-emitted organic carbon, CO_2, methane and other pollutants. The net change in warming from all these climatically important pollutants (taking into account the reflectivity of the underlying geography) will determine the overall near-term climate impact. Its long-term climate impact depends on whether the biomass is sustainably harvested, since the carbon from most biomass is taken up again when it is regrown (i.e., when forests grow back after firewood is harvested or grasses grow back after dung-producing animals graze).

CHAPTER

2 Hotspot Identification Methodology

What Is a Climate Change and Health "Hotspot"?

For the purpose of this paper a "hotspot" is defined as a country that is already experiencing, or is likely to experience, a changed burden of disease due either to: 1) the direct, ecosystem-mediated, or human system-mediated impacts of climate change (an "impact" hotspot); or 2) a population's exposure to emissions associated with the drivers of climate change, such as greenhouse gases or short-lived climate pollutants (an "emissions" hotspot).

Given that substantial work has been done on the health effects of both vulnerability to climate impacts and exposure to air pollution emission by country, we have built upon existing methodologies and datasets at the national level to answer the questions posed in this paper. However, there remain several gaps with respect to the ideal methodology for characterizing health outcomes in a detailed and comprehensive way at this level.

Identification of "Impact" Hotspots

There is no available comprehensive estimate of the change in burden of disease attributable to climate effects. While the burden of many climate-sensitive diseases has been identified, it is impossible to correlate the changes in incidence and prevalence of this burden with a specific change in climate versus other factors (let alone correlate a specific pathway with death and disease). This is the case both for acute natural disasters caused by climate extremes (heat waves, floods and drought, storm surges, typhoons, etc.), and progressive climate changes (increasing overall temperature and number of hot days, rising sea levels, etc.). The exceptions are a handful of climate-sensitive transmissible diseases.

The ultimate heath outcome of a disease is a function of, among other things, the exposure to the disease-causing factor, the genetics and socioenvironmental factors of the individual, the quality of health care, general socioeconomic development of the country and other mediating factors mentioned in Figure 1.2. Taking into consideration a few of these factors and the abundant literature on some diseases and accepted climate models, certain research/advocacy groups have developed composite indices attempting to quantify the effects of climate in a very limited number of transmissible diseases, as well as direct exposure to health impacts and nutrition.

Several widely used indices are described in Table 2.1 and assessed for their relative merits, including ND-GAIN, Climate Monitor, Center for Global Development, and the Global Climate Risk Index.

Based on a review of the indices, the ND-GAIN country index was chosen for its robust methodology for characterizing health vulnerability due to climate change and, in particular, for its specificity in including multiple health and human habitat impacts in its analysis that span the full range of recognized exposure pathways.

The ND-GAIN country index is a "living" index that is updated regularly but as used here it represents the November 2015 release of the 2014 indices. The ND-GAIN summarizes a country's vulnerability

Table 2.1: Comparative analysis of available vulnerability indices.

VULNERABILITY INDEX	APPROACH/SOURCES	ADVANTAGE	DISADVANTAGE
ND-GAIN	Considers most up-to-date literature to assess separate vulnerability through 2030 for six sectors that impact human well-being. Also provides a readiness index that assesses the overall country capacity (public, private and communities) to respond to climate change threats. The Health index includes diarrheal disease and malnutrition from Ebi (2008); malaria from Caminade et al. (2014); and number of malaria cases/1,000/ month from WHO Global Malaria Report (2013). This data is then moderated by slum population (UN Millennium Development Goals Indicators, 2015), access to sanitation and health systems performance proxies data from World Development Indicators (data.worldbank.org). The Human Habitat index relies on the Warm Spell Duration Index (Silliman et al., 2013) and monthly maximum precipitation in 5 consecutive days extracted from (Silliman et al., 2013). Urban concentration is a combined measure of the Herfindahl Index and population statistics as contained in the World Development Indicators.	• Systematic and transparent. • Comprehensive country coverage. • Includes principal causes of climate-related mortality (i.e., diarrheal disease, malnutrition, vector-borne disease) in a single, transparent "Health" metric based on recent, peer-reviewed scientific studies. • Direct climate-health pathways captured by "human habitat metric." • Covers 192 countries.	• Disability-adjusted life years (DALYs) are calculated for regions of the world and for groups of countries within the 14 different region groups. Thus, many countries share the same value of the measure. • "Readiness" to leverage private and public sector investment for adaptation actions is provided, albeit in a separate index, rather than integrated into vulnerability measures. This requires a separate step to include it within the metric as assessed by vulnerability alone (e.g., the "health" index).
DARA	Similar approach to ND-GAIN with respect to drawing on peer-reviewed studies and transforming these to systematize and normalize their use as an index. Meningitis indicator calculated based on S. Adamo (2011); All other impacts—McMichael (2004).	• More ambitious in scope with multiple indices for each sector requiring greater numbers of data transformations and methodological steps. More comprehensive categorization of health impacts (e.g., including meningitis). • Covers 184 countries.	• Less straightforward presentation of results requires greater effort to interpret and understand results. • Based on older data sets (McMichael, 2004, uses underlying disease data from 2000) and posters as opposed to peer-reviewed publications (Adamo, 2011). • Many separate indices (e.g., climate vs. carbon) that require integration.

VULNERABILITY INDEX	APPROACH/SOURCES	ADVANTAGE	DISADVANTAGE
Wheeler Index	Develops country impact indicators for three critical dimensions of climate change: more extreme weather, sea level rise and loss of agricultural productivity. Based on econometric analysis of EM-DAT database (extreme weather; Dasgupta et al., 2009a, b [SLR]), and agricultural productivity (Cline, 2007).	• Integrates social factors and vulnerability factors (including determinants of resilience, namely economic development, demographic change, and governance) into a set of metrics by climate impact type, allowing for consideration of individual categories of disease. • Comprehensive jurisdictional coverage with 233 countries represented (including 20 small, low-income island states).	• Not health specific, thereby requiring a step to combine health data with climate vulnerability data.
German Watch Global Climate Risk Index	Based on damage and loss for more than 159 countries between 1994 and 2013, based on reporting by Munich Re NatCatSERVICE and economic and population indicators from the International Monetary Fund (IMF). Indicators include: (i) number of deaths, (ii) number of deaths per 100,000 inhabitants, (iii) sum of losses in US$ in purchasing power parity (PPP) as well as (iv) losses per unit of gross domestic product (GDP).	• Based on actual data.	• Only a single category of vulnerability. • Not health specific. • Within loss and damage due to storms, the indicator does not take into account important aspects such as sea-level rise, glacier melting or more acidic and warmer seas.

ND-GAIN: University of Notre Dame Global Adaptation Index. http://index.gain.org
DARA Climate Vulnerability Monitor v2. http://daraint.org/climate-vulnerability-monitor/climate-vulnerability-monitor- 2012/
Wheeler (2011). Quantifying Vulnerability to Climate Change: Implications for Adaptation Assistance,
Working Paper 240, Center for Global Development. http://www.cgdev.org/publication/quantifying-vulnerability-climate-change-implications-adaptation-assistance-working
German Watch Global Climate Risk Index 2015. https://germanwatch.org/en/download/10333.pdf

to climate change and other global challenges in combination with its readiness to improve resilience through the development of a two-part suite of indices. *Vulnerability* is assessed by means of six sectors including: ecosystem services, food, health, human habitat, infrastructure, and water. The underlying factors that contribute to vulnerability within each of these sectors are built into the index. *Readiness* is assessed through economic factors (essentially the "Doing Business" ranking published by the International Finance Corp.) and governance and social factors, including social inequality, information communications technology infrastructure, education, and innovation.

The "Health" subindex would appear to be the most relevant basis for assessing individual country vulnerability to climate impacts. A review of the methodology reveals that this index includes proxy data for exposure to vector-borne disease (i.e., malaria), food- and waterborne infectious disease (diarrheal disease), and famine (malnutrition), influenced by socioeconomic factors like access to sanitation and adequate housing, and proxies for health system performance. However, based on the IPCC typology of climate exposure pathways (Chapter 1), the ND-GAIN "Health" subindex omits the direct exposure pathway that includes increased heat extreme and flood and storm exposure. The ND-GAIN "Human Habitat" subindex does, however, include proxy data that measure "projected change of heatwave hazard, projected change of flood hazard, urban concentration, age dependency ratio, quality of transport and trade infrastructure, and paved roads."

These two subindices are the best current metrics by which we can establish a list of priority countries for action without conducting a detailed research study. The two vulnerability subindices selected (Health and Human Habitat) are compared against each other and this serves to identify all countries that lie more than one standard deviation beyond the median value of vulnerability for each subindex. The "Readiness" Index is used as a third dimension to assess where country capacity can reduce biophysical vulnerability. Together, these steps generate a set of countries that face the greatest potential challenges with respect to the pathways of climate exposure identified by the IPCC. We have included a qualitative description of key factors that determine climate health impact to provide a more comprehensive picture of geographically correlated climate-sensitive health impacts.

Identification of Emissions Hotspots

As noted, there is a strong association between sources of fine airborne particulates (referred to as $PM_{2.5}$), other forms of air pollution, and sources of either greenhouse gases GHGs or SLCPs. It is also clear that black carbon and many other co-emitted fine particulate species play a strong role in influencing climate change. However, the role of aggregate (i.e., undifferentiated) $PM_{2.5}$ mass in warming the climate is complex, as some types (like black carbon) lead to strong warming and others (such as sulfate aerosol) generate significant cooling. We simply note here that not all fine particulate pollution affects climate the same way. In fact, the uncertainties associated with aerosols and their impact on the climate system are among the largest remaining research challenges facing climate scientists. Given the large overlap between sources of combustion-related $PM_{2.5}$ and greenhouse gases, we simply note that health, climate and other development benefits need to be fully considered when assessing control options.

While more work is needed to untangle the climate and health impacts of various emission sources at a global and national level, the Institute for Health Metrics and Evaluation (IHME) at the University of Washington has already drawn a connection between burden of disease health outcomes (including respiratory, cardiac, and cancer risks) to the observed levels of air pollution. There have been independent assessments of both ambient air pollution—which is co-emitted with a range of sources that contribute to accumulation of greenhouse gases—and household air pollution (one of the largest aggregate sources of the short-lived climate pollutant, black carbon). The IHME data are 2013 statistics that have then been aggregated at the country level (IHME, 2015).

Using the Global Burden of Disease data, we carried out two distinct analyses. The first characterized countries in terms of their burden of disease due to climate drivers (air pollution), with respect to other countries (an intercountry comparison). The analysis was performed initially in terms of absolute burden, and then normalized by population (disability-adjusted life years per 10,000) to correct for country size. However, while this approach provides a comparative view of countries' burden of disease, it does not indicate the significance of air pollution when viewed against other major causes of death or illness—such as malnutrition or sexually transmitted diseases—in each country.

Accordingly, we used an alternative approach to look at the national impact of air pollution within a country relative to other health risk factors. Here we again made use of the global burden of disease statistics to identify all countries in which household

Box 2.1: Identifying Climate Health Impact Hotspots within Countries

Adopting an integrated approach to address climate change and health is of particular importance *within* countries because it is at this level that there is potential for policy adoption, regulation, and ground-level action. Identifying health impact hotspots in a country differs from the approach to mapping them globally or regionally. At the macro level, identification of impact hotspots relies on global indices and very large global data sets. At the country level, there is a need for different tools to identify geographies for action, such as data on land use, vegetation, the built environment, and others. Because we are working with smaller data sets, we can better hone in on the precise areas of impact, correlated to human habitat type (ecological or built) and show more faithful correlation to climate health impact than a geographic region defined political boundary.

Unfortunately, an approach that focuses within national borders has not been attempted with any degree of comprehension. It has, however, been performed for specific diseases, such as malaria and dengue, to identify present and future impact areas. Different habitat types are parameterized and geographies of greatest current and potential threats then identified. For historic data, results can be compared to health data to determine accuracy.

The precise type of habitat to map will vary by health impact but will include a mix of natural and built environments. For example, dengue is prone in regions that are hotter, wetter, and often urban; whereas malaria typically only correlates to areas that are hotter, wetter, and rural. Other considerations, such as proximity to swamps, deserts, bodies of water, roads, population can be used in disease-specific mapping. A list of different habitat-related environmental determinants of disease should be generated prior to starting such an exercise, and correlated to health impacts to ensure most comprehensive results.

Because such a step needs to be performed for only one country, it is best to do this individually for a number of different climate and health impacts, which again, is different than the global work that combines these impact types to produce a composite index. Impact hotspot areas for specific diseases within a country are then mapped out. This data can then be compared against health data, which is often collected at a subnational (county/district) level for validation.

air pollution ranked within the top five national health risk factors and those countries where ambient air pollution was among the top nine national health risk factors. In both cases, we used the Global Burden of Disease "Level-4" risk factors, which refer to the level of disaggregation of risk factors. We chose these (admittedly arbitrary) thresholds as they provide a number of hotspots (~ 28 ambient air pollution, ~ 39 household air pollution countries) similar to that of the intercountry comparison. Finally, we analyzed the intersection of the results from the two methods. That comparison is presented separately in Chapter 3.

Additionally, various analyses have been reviewed that identify the greatest benefits of various climate mitigation interventions that can be achieved for specific sectors (i.e., where sector-specific interventions are likely to yield the greatest health benefits). This second analysis provides verification that the identified emissions hotspots (based on *existing* pollution levels) are also areas that will benefit from potential mitigation responses.

Caveats and Limitations of This Analysis

Trying to identify national hotspots is a difficult task as the ecosystems (as well as biophysical and geographical factors that affect climate and emissions health impacts) do not map to country boundaries. Rising sea levels affect primarily coastal areas, as do storm surges, while cities suffer from the heat island effects, intensifying the impact of heat waves. Nevertheless, given that the World Bank works at the country level, this remains the most appropriate basis for analysis.

While national hotspots have been identified using the data and following the methods described above, these national aggregations of climate risk will miss some areas of highly concentrated vulnerability that occur at the subnational level. The first section of Chapter 3 attempts to address this limitation by providing a qualitative description of the geographies and scales at which various vulnerabilities occur. Table 3.1 describes the factors involved in developing a more detailed, subnational vulnerability assessment, but we acknowledge that the current report does not provide such a level of detail.

Similar limitations also apply when considering emission hotspots at the national level. Air quality is typically an urban phenomenon attributable to the concentrated emissions of thousands of individuals, businesses, or activities without adequate space (related to the atmospheric volume) necessary to disperse and break down pollutants at a rate to avoid the buildup of unacceptable levels of pollution. While the regional pattern of city location, geography, and regulatory structures can make some nations more susceptible to poor air quality, hotspots are more naturally identified at the municipal scale than the national scale. Identifying hotspots based on national burden of disease attributable to air pollution will be skewed toward countries that are geographically large, with big populations. The national-level approach to estimate "population-normalized" burdens of disease does not account for variation in geographic size, which may introduce a bias for countries with extremely high or low population densities. Nevertheless, for the reasons already stated, we have used these and other statistics to identify national hotspots.

We acknowledge that in taking the national approach, we have also relied on available statistics that may potentially underestimate risk and exposure in some locations. The earlier Global Burden of Disease data (IHME, 2010) had relied on satellite-based measurements of total-column $PM_{2.5}$ to estimate surface level $PM_{2.5}$ concentrations where measurements are unavailable. Recent work has shown that in some cases, this may underestimate surface concentrations and—therefore—human exposure in areas that lack ground-based monitors, particularly in regions with high wintertime and nighttime concentrations where satellite data is lacking (Van Donkelaar et al., 2015). To address some of these deficiencies, 2013 Global Burden of Disease estimates make use of vertical profile data, updated inventories and sub-grid-scale urban exposure algorithms to improve estimates relative to 2010 results (Brauer et al., 2015).

Finally, we recognize that not all sources of pollution are anthropogenic or related to combustion, as is the case with sea salt and mineral dust aerosols. While there are health impacts associated with all components of fine particle pollution, there is less scope for addressing natural particle emissions.

CHAPTER

3

Hotspots

Assessing "Impact" Hotspots Associated with Climate Effects

As stated, the impacts of climate change do not follow country boundaries but as the World Bank's operational work and policy dialogues are country-driven, we assess and present "impact" hotspots at the national level. Nevertheless, there are many ways to characterize both climate-sensitive health impacts and the geographies to which they correlate; many of those either cut across countries or describe variability within a country. Some of the most salient are discussed below.

Tropical and equatorial latitudes have been identified as more vulnerable to illness and disease due to heat. These impacts will also be greatest in **cities**, which amplify heat effects. Additional studies have suggested that heat will be a particularly significant problem for South Asia (Takahashi et al., 2007, as cited in The World Bank, 2013) and Sub-Saharan Africa, especially inland populations with limited water supplies.

Populations in flood plains, in small catchments and on coasts are most susceptible to floods and storms, particularly in the tropics where heavy rain and storm events are most common. Asia, Africa, and Central and South America also have been highlighted by IPCC (Smith et al., 2014).

Those regions most vulnerable for vector-borne disease include: for malaria, Africa and Southeast Asia; for Dengue, Asia/Pacific; for Lyme disease, temperate areas of Europe, Asia and North America. Encephalitis is present in Europe, Russia, Mongolia, and China. Hemorrhagic fever occurs globally (Smith et al., 2014; World Bank, 2013), dengue is more frequent in cities, and leishmaniasis—spread by sand flies—is common in desert regions.

Food- and waterborne diseases are projected to have significant impacts in Southeast Asia (Kolstad & Johansson, 2011, as cited in World Bank, 2013). Models suggest Sub-Saharan Africa, South Asia, East Asia and the Pacific are the regions most susceptible to food system disruptions due to climate change (Lloyd et al., 2011, as cited in World Bank, 2013).

Table 3.1: Geographic correlations to climate-sensitive health impacts.

	DIRECT IMPACTS		ECOSYSTEM-MEDIATED			HUMAN INSTITUTION-MEDIATED
	HEAT AND COLD	FLOODS AND STORMS	VECTOR-BORNE DISEASE	FOOD AND WATERBORNE INFECTION	AIR QUALITY	UNDERNUTRITION
Geographies of greatest impact	Lower latitudes	Low-lying areas/ flood plains	Tropics—variable by disease	Tropics	SE Asia	Sub-Saharan Africa
	Cities	Coasts	Dengue: South American cities	Subtropics	Cities	East Asia and Pacific
	South Asia	Tropics	Leishmaniasis: desert	SE Asia	India	Latin America
	Sub-Saharan Africa	Asia	Encephalitis: Europe, Russia, Mongolia, China	Low-lying areas	China	Sahel
		Africa	Upland mountains with population pressure	Food insecure regions	Pakistan	Conflict zones
		Central/South America		Cholera—SE Asia	Sub-Saharan Africa household pollution	Upland mountains with population pressures
		Atolls				

Source: Authors.

Country Characterization Using ND-GAIN Indexes

As indicated in the methodology section, to identify national vulnerability we can plot the distribution of countries as shown in Figure 3.1, where the ND-GAIN Health Index (a proxy for ecosystem- and human system-mediated pathways) is plotted against the Human Habitat index (proxy for direct exposure pathways) for 2014. There is a fairly high degree of correlation between the two, with many countries in the upper right hand corner of the graph exhibiting higher vulnerability to both direct and mediated health impacts.[5] This provides a sense of which countries will also require higher levels of support in the areas of governance, business climate and social capacity. These countries likely will be less able to cope with the systemic stresses thrown at them by climate change impacts. Yellow shading indicates countries that lie at least one standard deviation above the median value of the complete sample. In order to best identify the extremes revealed in this sample, the upper right quadrant has been enlarged and reproduced in Figure 3.2. Here the dotted lines indicate regions that lie at least 1 standard deviation above the median of the full sample for *both* indices.

The proposed set of climate-sensitive "impact" hotspot countries are listed in Figure 3.3 and shown in Figure 3.4. Figure 3.3

5 The "Health" subindex assesses the projected variation in expected deaths from climate change-induced diseases (diarrhea and malnutrition), projected change of malaria hazard, dependency on external resources for health services, slum populations, medical staff, and access to improved sanitation facilities. The "Human Habitat" subindex assesses vulnerability of human living conditions to climate change, considering weather extremes, urban development, demography, and transport infrastructure. Indicators include: projected change of heatwave hazard, projected change of flood hazard, urban concentration, age dependency ratio, quality of transport and trade infrastructure, and paved roads. Both subindices incorporate aspects of ecosystem response through the underlying climate modeling on which the two different aspects of risk are measured. This inclusion of ecosystem response in both subindices is necessary to accurately reflect both sets of risk, but is not the cause of the observed correlation.

Figure 3.1: Identifying vulnerable countries using ND-GAIN subindexes.

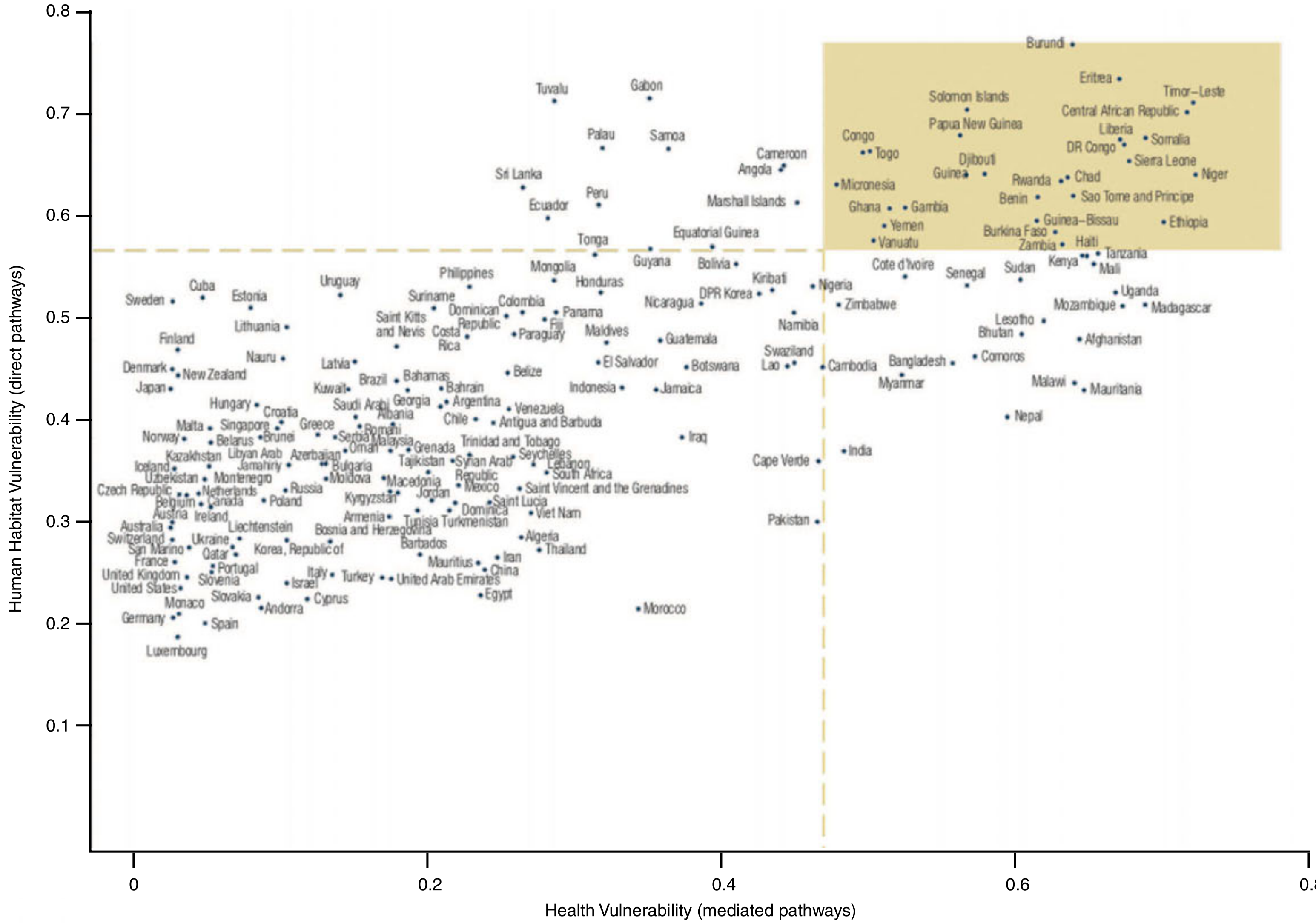
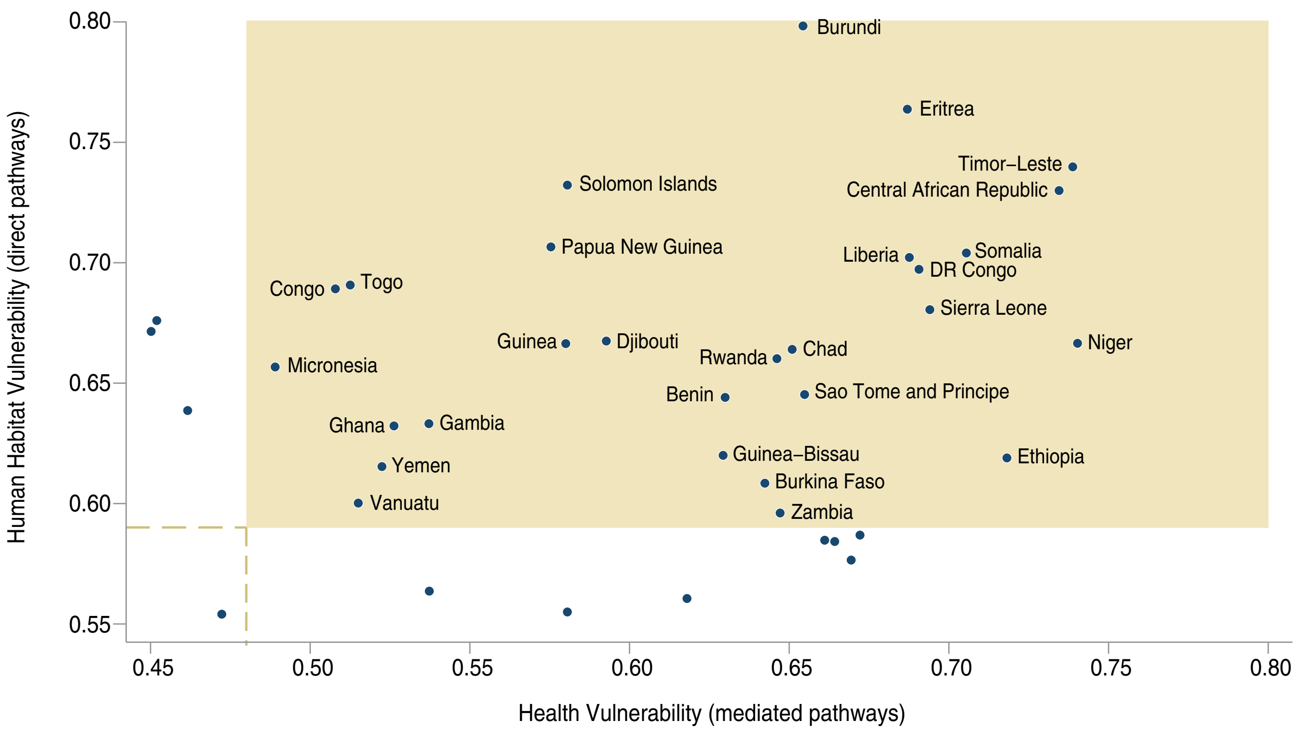


Figure 3.2: Highly vulnerable countries by ND-GAIN Health and Human Habitat indexes (inset of Figure 3.1).



assigns those countries at elevated risk into three groups. Those in the green color are at higher comparative risk in both the Human Habitat and Health dimensions. Those in the gold and blue colors are at elevated risk in one dimension or the other. Figure 3.4 shows their locations on the map.

Hotspots Associated with Emissions, the Drivers of Climate Change

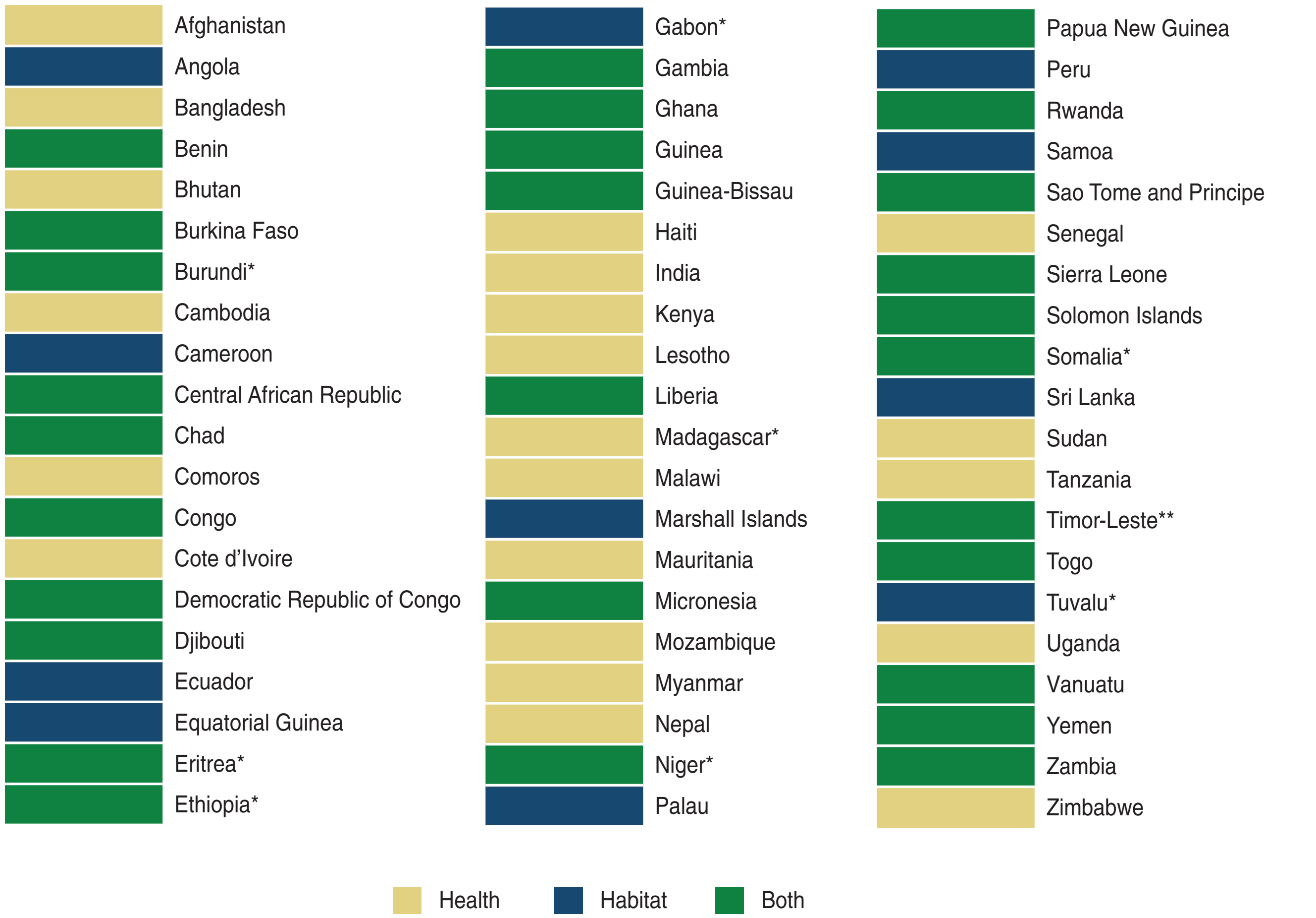
The best means of assessing health impacts of climate-driving emissions is to acknowledge the high degree of overlap between drivers of climate change and air pollution sources of all types. A geographic analysis of the drivers of climate change is presented in Annex B, however the most direct link between health and emissions is the co-emitted pollutant fine particulate matter, or $PM_{2.5}$, rather than greenhouse gases or short-lived climate pollutants. Therefore, the hotspot analysis here focuses on data addressing the burden of disease attributable to both ambient air pollution and household air pollution for 2013 developed by the Institute of Health Metrics and Evaluation and the Health Effects Institute for the World Bank (IHME, 2015).

Intercountry Comparison

IHME 2013 burden of disease data have been used to develop indicators of health burden (both in absolute terms and normalized by population) attributable to individual countries and are presented in Annex C. Figure 3.5 shows the burden of disease attributable to ambient air pollution and household air pollution. The tables in Annex C and Figure 3.5 reveal a significant degree of commonality between countries affected by ambient air pollution (AAP) and household air pollution (HAP), but also important distinguishing characteristics of countries affected by one or the other, but not both.

China and India have the highest total burden of disease due primarily to their very large populations that are routinely exposed to ambient and household air pollution. These two countries alone account for half of the global burden of both ambient and

Figure 3.3: Characterization of climate-sensitive "impact" hotspots based on ND-GAIN.



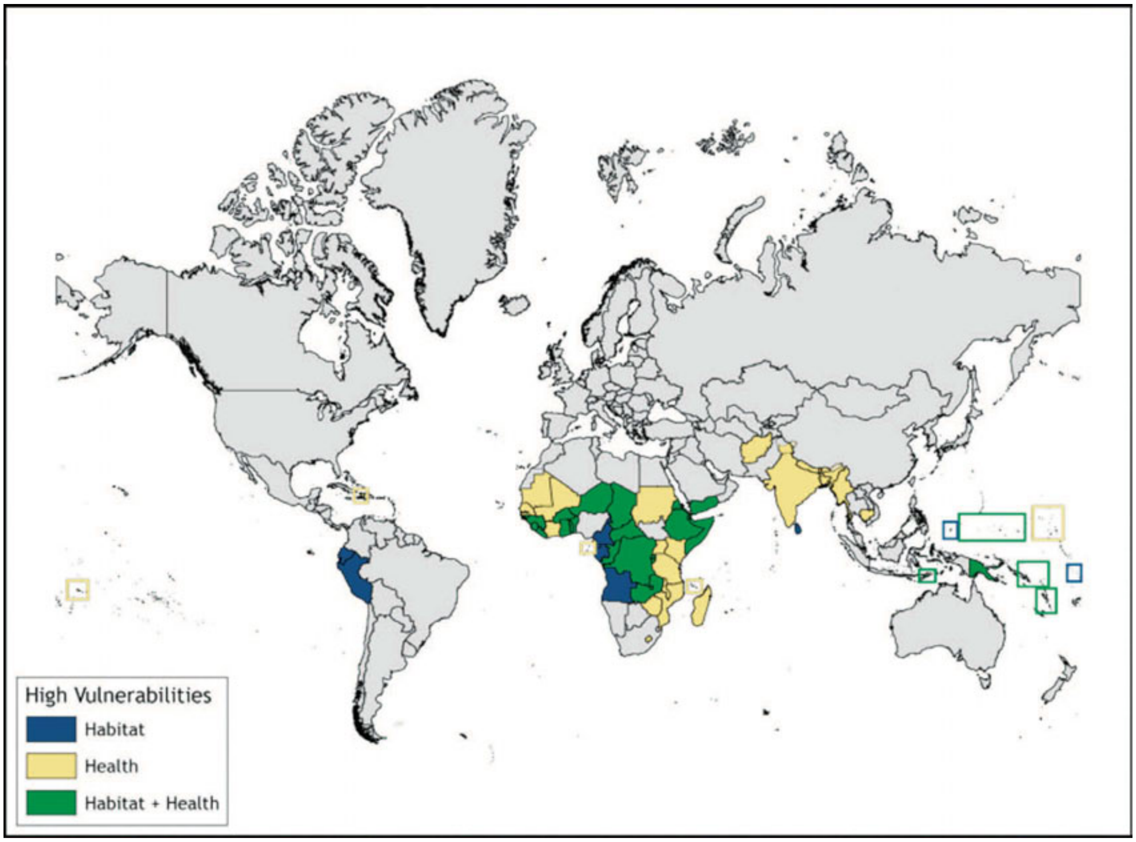
Source: Authors.
*At highest risk (i.e., more than two standard deviations above median).
**At highest risk in both health and habitat dimensions.

household air pollution, when considering mortality and morbidity in disability-adjusted life years (DALYs). Together they represent 52 and 60 percent of premature mortalities from ambient and household air pollution, respectively. However, looking exclusively at national burdens in absolute terms obscures the fact that many other countries suffer a disproportionately high burden of disease at the individual level. Anyone who has struggled to breathe or to see through a thick layer of smog in a country with a small population like Mongolia can attest to this fact.

While a strict ranking of population exposed to various types of air pollution is useful for identifying areas where the climate-health threats are greatest, additional analysis is needed in proposing or developing appropriate mitigation responses in various locations. Therefore, in addition to characterizing the countries by their overall burden, we also present the data normalized by population. For example, Figure 3.6 compares the population-normalized burden of disease associated with ambient air pollution to the normalized burden due to household air pollution. While there is strong correlation for many countries, a few typologies quickly reveal themselves.

Burden of disease is normalized by population and presented in DALYs per 10,000 people for 2013. Countries within the yellow

Figure 3.4: Climate "impact" hotspots.



shaded area represent countries that are more than one standard deviation above the median level of either ambient or household air pollution observed in all countries (or both). Countries within the green zone have a statistically significant (two standard deviations) elevation of ambient or household air pollution (or both) and countries within the purple zone have unusually high elevation of ambient pollution (Turkmenistan), household pollution (Somalia), or both (Chad, Afghanistan).

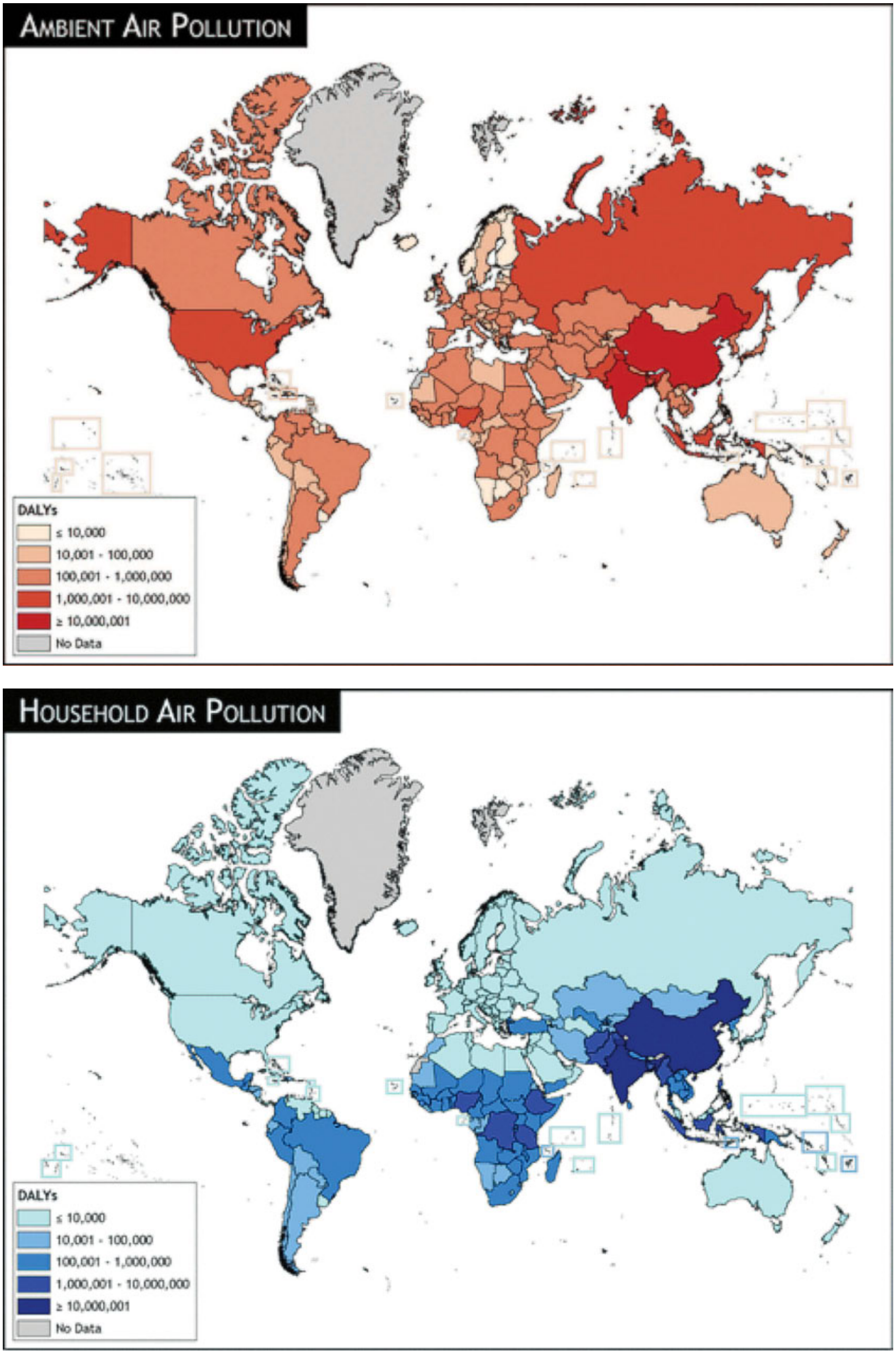
Afghanistan, Chad, Central African Republic, Guinea Bissau, Sierra Leone, and **Mali** stand out as having populations exposed to multiple air pollution-related health threats. In these countries, significant use of biomass fuel for home purposes results in the emission of black carbon and other components of fine particulate matter. This contributes—in part—to the existing ambient air pollution, which itself stems from many different combustion sources that may also emit CO_2. Countries with easy access to modern fuels for cooking and heating are also likely to have significant emissions from other modern conveniences such as power plants and vehicles. Thus **Turkmenistan, Belarus, Ukraine, Bulgaria,** and **Moldova** have high burdens of disease attributable to ambient air pollution, but not household air pollution.

Figure 3.7 zooms in on the upper right quadrant so that we get a closer look at countries that lie significantly outside the range of others in terms of both household and ambient air pollution **(Afghanistan, Chad, Central African Republic, Guinea-Bissau, Mali, Sierra Leone, South Sudan, Democratic Republic of Congo, Niger, North Korea, Guinea, and Laos).**

A second tier of countries with significant levels of both ambient and household air pollution that may require comprehensive responses to address access to modern fuels as well as other emission sources emerges in Figure 3.7 (i.e., **Cambodia, Burkina Faso, Cote d'Ivoire, Myanmar,** and **Cameroon**).

In Figure 3.6, we can easily distinguish another cluster of countries, including **Somalia, Madagascar, Malawi, Equatorial**

Figure 3.5: 2013 burden of disease attributable to ambient air pollution (top panel) and household air pollution (bottom).



Source: Institute for Health Metrics and Evaluation (IHME, 2015). From Global Burden of Diseases, Injuries, and Risk Factors Study, aggregated by country in disability-adjusted life years (DALYs).

Figure 3.6: 2013 burden of disease attributable to ambient versus household air pollution (2013).

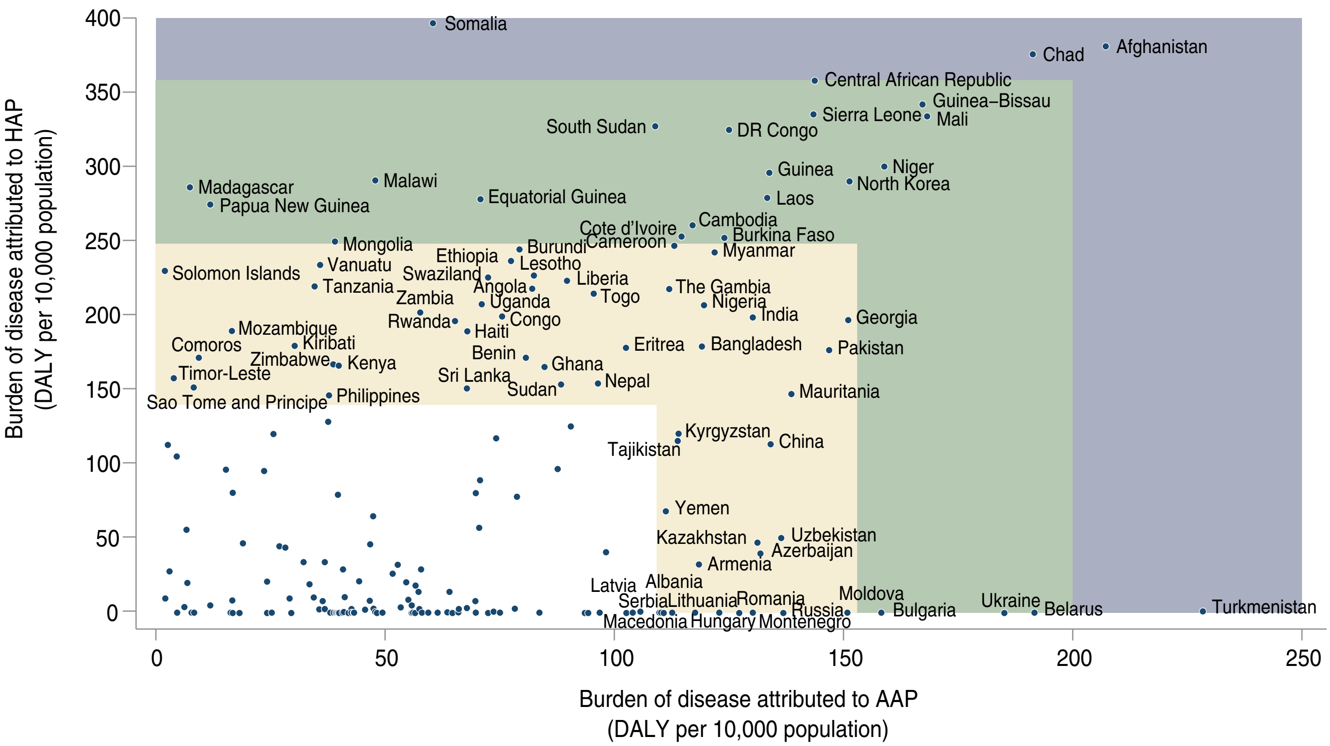
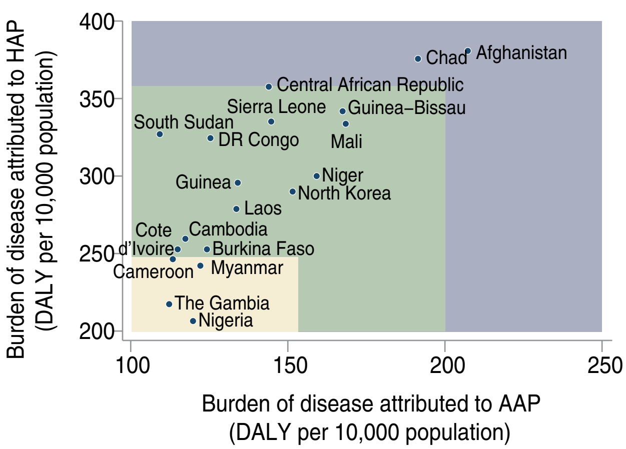


Figure 3.7: Burden of disease attributable to ambient versus household air pollution: Extremely impacted countries (2013).



Guinea, Papua New Guinea, and **Mongolia** that would benefit from strategies with a focus on reducing short-lived climate pollutants and other emissions associated with household air pollution. Each of these countries has a level of household air pollution death and illness more than two standard deviations above the median. Yet not one of these countries has the same distinction with respect to ambient air pollution deaths. Operational approaches to address the climate and health linkages within each of these countries therefore should recognize that it is essential to build health systems that can address the *current* burden of disease associated with current residential cooking and lighting technologies while simultaneously considering how that burden can be eliminated through access to modern fuels. Such planning should also encompass the broader goal of putting the country on a path to zero net carbon emissions by the end of the century. Each of these countries also appears on the list as having among the 100 least efficient health systems, pointing to lower capacity to undertake adaptive measures or prevention programs.

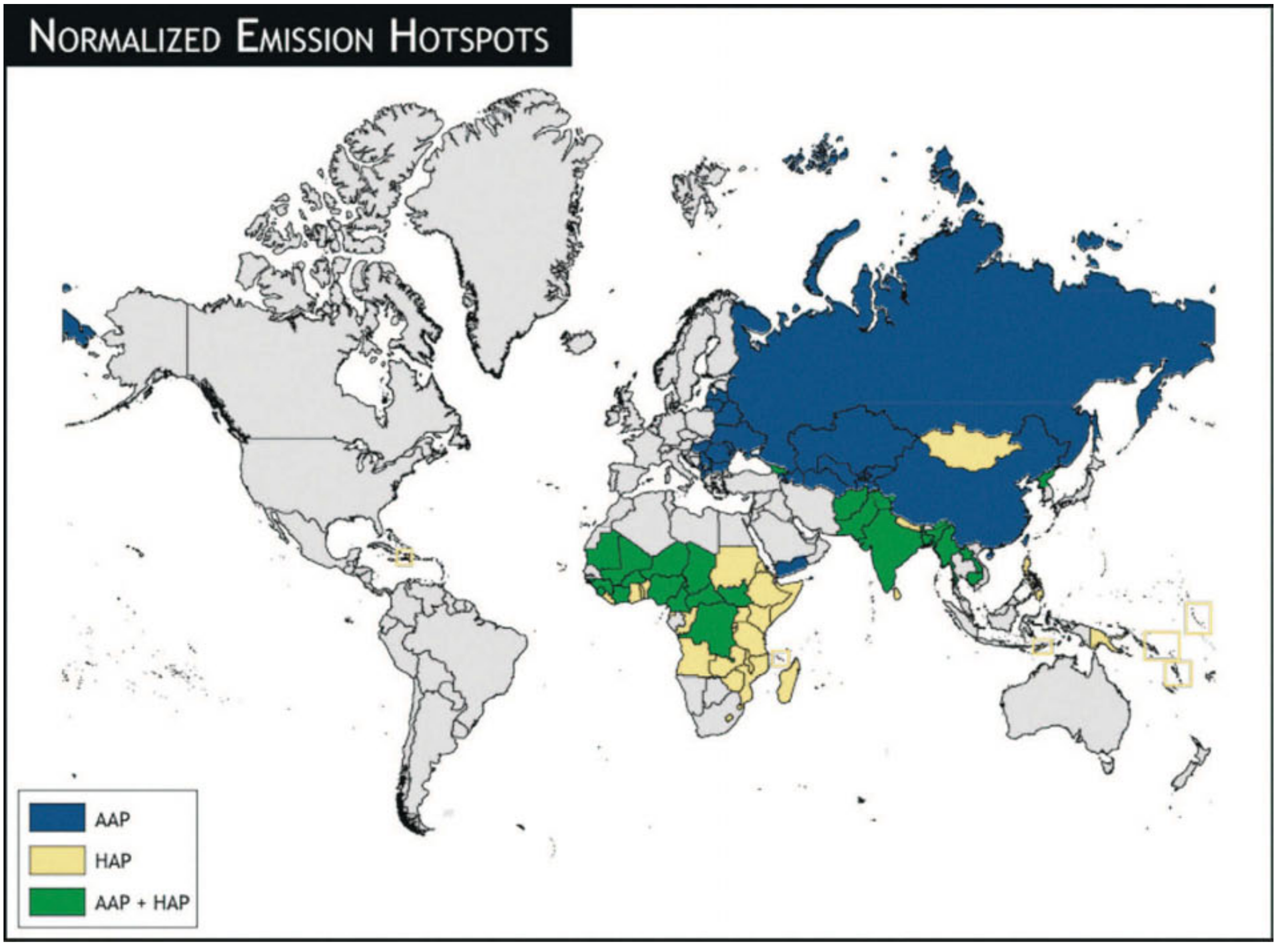
Countries such as Kyrgyzstan, Tajikistan, China, Uzbekistan, Kazakhstan, Yemen, Armenia, and **Azerbaijan** each have a level of normalized ambient air pollution incidence of death and disease that is more than one standard deviation above the median, but none has that level of departure from the median with respect to household air pollution. The countries in this group have made progress in the shift to modern fuels for heating and

Figure 3.8: Characterization of climate-driver "burden" hotspots based on Global Burden of Disease.

Note: In this figure, the gold color indicates the respective populations normalized burden of ambient air pollution (AAP) more than one standard deviation above the median of all countries. The blue color indicates the respective populations normalized burden of household air pollution (HAP) more than one standard deviation above the median of all countries. The green color indicates the respective populations normalized burden of both AAP and HAP more than one standard deviation above the median of all countries.

cooking; however, access to, versus the sustainable use of, natural resources are two different things. The toll that air pollution is taking on these societies indicates inefficient use of their natural resources that results in excess air pollution. Operational guidance for these countries should be to orient climate and public health policies to move away from CO_2 and the co-emitted contributions to ambient air pollution that are elevating their health risks. This is quite a different task than addressing the energy access concerns of the prior list of countries. Figure 3.8 lists these countries and Figure 3.9 maps these results globally.

Figure 3.9: Countries with elevated (population normalized) burden of disease attributable to ambient air pollution (AAP, blue), household air pollution (HAP, yellow) or both (green).



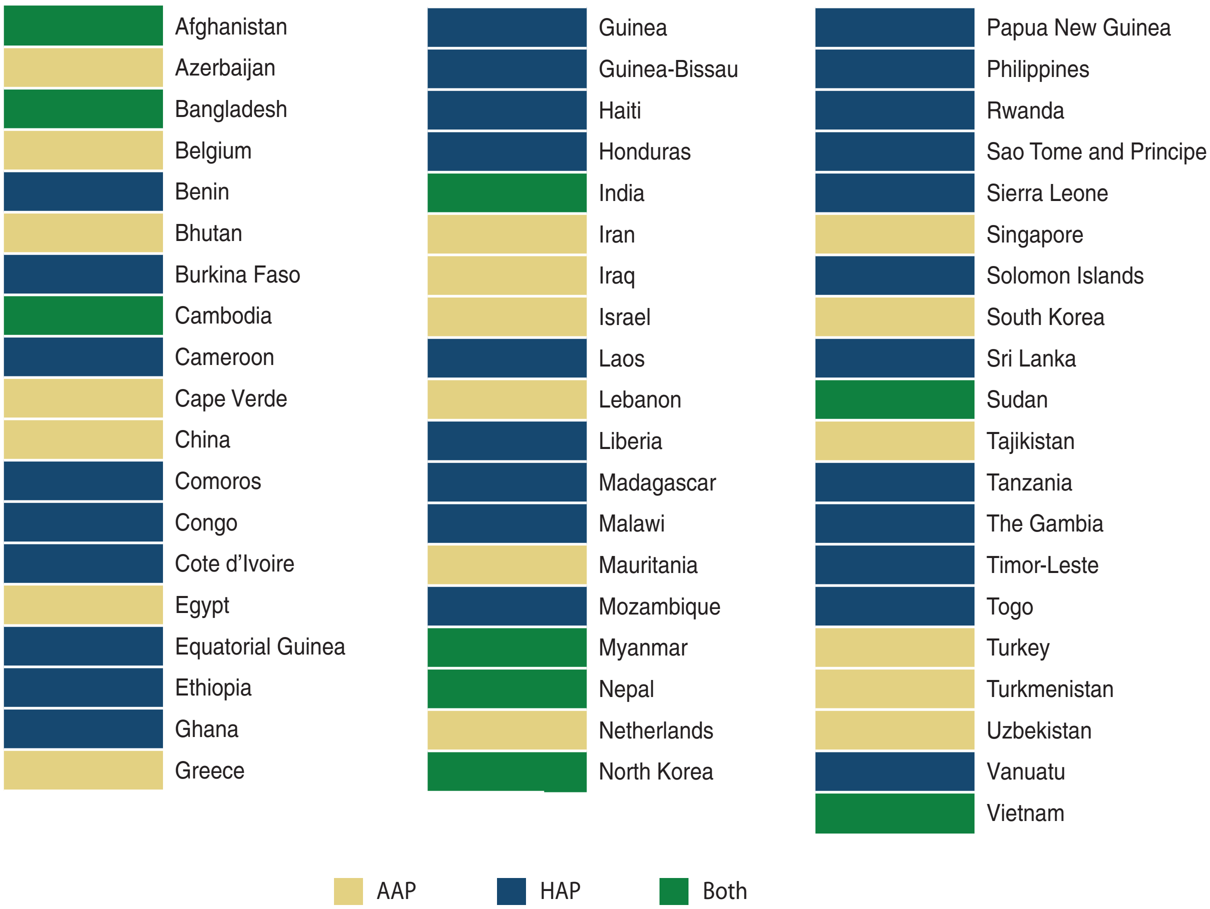
Intra-Country Comparison

An alternative approach for identifying countries with increased health risk associated with ambient air pollution, household air pollution or both also uses 2013 statistics from the Global Burden of Disease (GBD) project, but does not rely on intercountry comparisons. The GBD also assessed the risk of both types of air pollution relative to other in-country health risks for each country. By selecting those countries where household air pollution ranks within the top five national health risks and those countries where ambient air pollution ranks within the top nine national health risks, we find a similar sample size (~28 ambient countries; ~39 household air pollution countries) to the other metrics. Figure 3.10 lists these countries and Figure 3.11 maps them utilizing the same color scheme as for Figure 3.9.

Intersection of Intercountry and Intra-Country Methods

While there are advantages and disadvantages to each approach for assessing which countries are in greatest need of addressing emission-related health impacts, the most robust set of hotspots will be found by looking at the intersection of both methods. In Table 3.2, a country appears as a hotspot with respect to ambient air pollution (AAP) if it was (a) found to have a significantly elevated population-adjusted burden of disease due to AAP, *and* (b) AAP

Figure 3.10: Characterization of climate-driver "risk" hotspots based on Global Burden of Disease.

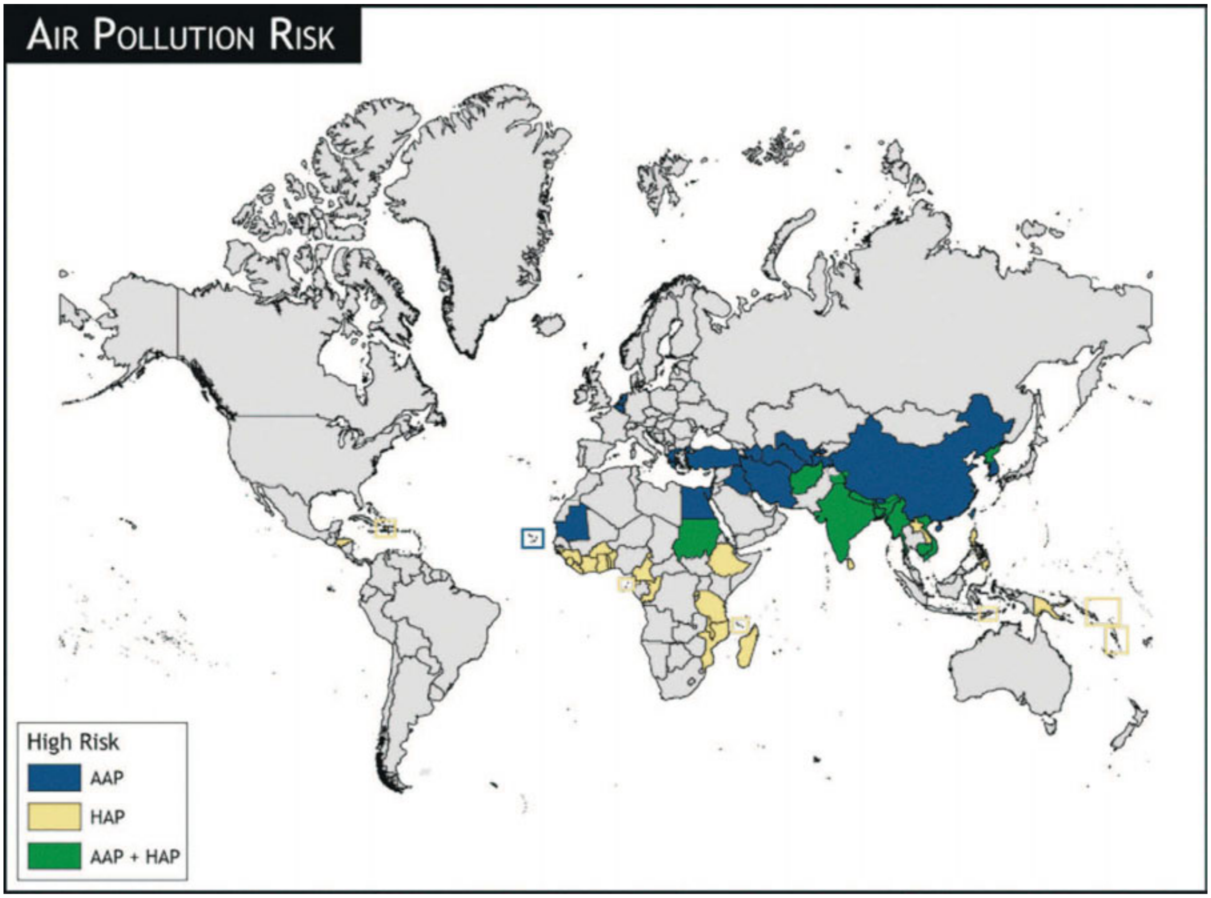


Note: In this figure, the gold color indicates the respective populations with AAP ranking within the top nine national health risks. The blue color indicates the respective populations with HAP ranking within the top five national health risks. Green indicates the respective populations with both AAP ranking within the top nine national health risks and HAP ranking within the top five national health risks.

was found to be among the countries nine most-significant health risks. Similarly, a country appears in Table 3.2 as a household air pollution (HAP) hotspot if it was (c) found to have a significantly elevated population-adjusted burden of disease due to HAP, *and* (d) HAP was found to be among the countries top five health risks. A country is listed as a "Both" hotspot only if conditions (a), (b), (c), *and* (d) are met. Those countries that satisfy conditions (a) and (c) but only one of conditions (b) or (d) are indicated by an asterisk. Nepal satisfied condition (b), (c), and (d) but was not an AAP hotspot by the 'burden' approach.

This intersection method of identifying national-level hotspots is instructive as well as validating. For example, it makes clear that with respect to ambient air pollution, targeting the countries with the highest per-capita health burden from air pollution does not target the same countries where air pollution is among the top health risks. As such, the list of "intersection" hotspots is much shorter than either of the individual approaches. Some countries clearly have a relatively high share of people suffering from ambient air pollution, but also have other, more pressing health risks (e.g., Lithuania, Macedonia, Romania). Whereas other countries have ambient air pollution as one of the most significant health risks to the population, but they do not have a high relative burden; they are just very healthy societies (e.g., Netherlands, Belgium). A unique set of counties emerges from the intersection. Many of the ambient air pollution hotspots identified by both methods (e.g., Tajikistan, Turkmenistan, Kazakhstan) share access to modern fuels,

Figure 3.11: Countries in which ambient (blue), household (yellow) or both types of air pollution (green) rank highly in their burden of disease.

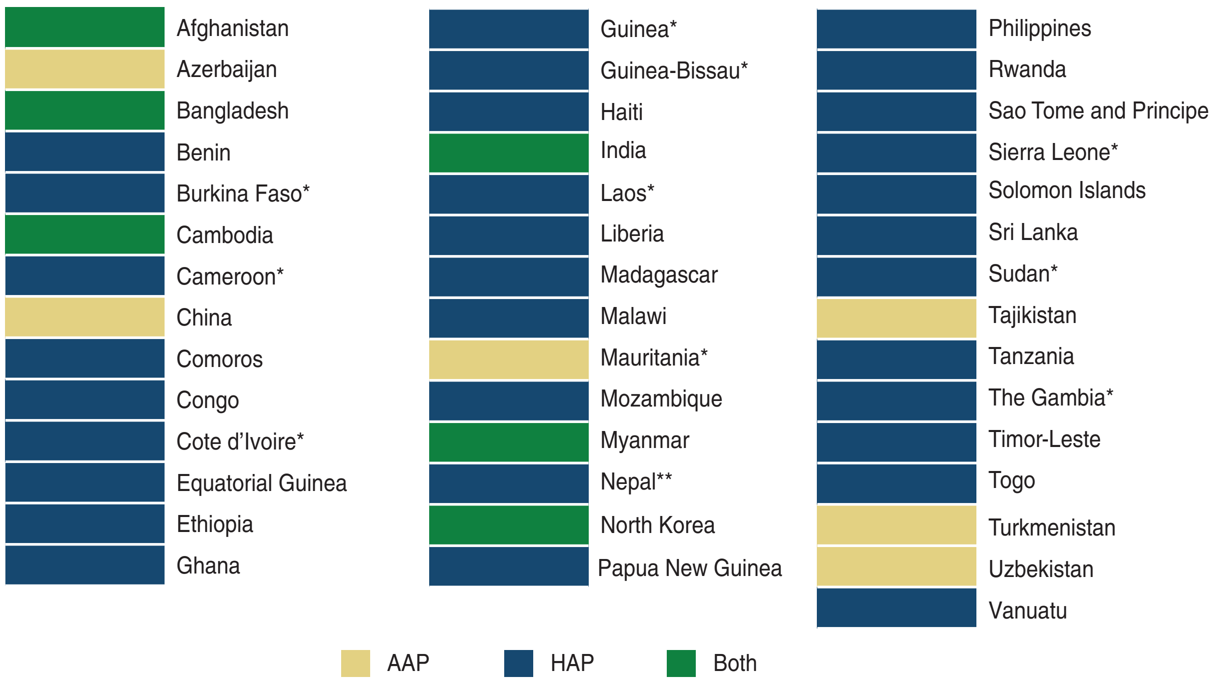


and thus are not on the list of household air pollution countries, but they use these modern fuels very inefficiently, resulting in excess air pollution. This has direct implications for the operations that would be needed to address ambient air pollution in these countries that is distinct from programs to address household air pollution or countries that suffer from both.

It is also notable that the list of household air pollution hotspots is strikingly similar across methods and thus there is a long list (almost the entire list) identified at the intersection between methods. This implies that there is a very robust association with these countries and that clearly these countries—where household air pollution is a top health risk and exacts a high toll—must address household air pollution as an aspect of public health and climate operations.

Additional analysis is needed at the national level to determine specific mitigation approaches that will best balance climate and health considerations for countries that face simultaneous challenges to health through ambient *and* household air pollution. Determining the optimal balance for the many countries that are in between these poles requires a more concerted effort to assess all sources of health risk linked to climate changes, as well as the mitigation options (both now, and in the future). Tailored development plans must address those urgent health priorities that are contributing to the current burden of disease, as well as reduce the impact of, and appropriately transition away from, those sources found to be the drivers of future climate change.

Figure 3.12: Emissions hotspots. Note that countries listed in each category represent countries with elevated, population-normalized burden of disease.



Source: Authors.
Notes:
* Met criteria for BOTH based on burden approach, but only AAP or HAP criterion by risk approach.
** Met criteria for BOTH based on risk approach, but only HAP criterion by burden approach.
AAP = ambient air pollution. In this figure, the gold color indicates the countries with the AAP burden more than 1 standard deviation above the median and in the top 9 national risks. HAP = household air pollution. In this figure, the blue color indicates the countries with the HAP burden more than 1 standard deviation above the median and in the top 5 national risks. Both = both AAP and HAP. In this figure, the green color indicates the countries with the AAP burden more than 1 standard deviation above the median and the HAP risk in the top 5 national risks.

CHAPTER

4

What Can Be Done: Adaptation and Mitigation

Global average temperature increases due to climate change are expected to increase the frequency and severity of extreme weather events, as well as climate variability. As has already been observed, these events are and will continue affecting health outcomes, mostly negatively. These impacts could slow or, on occasion, even reverse the decades-long trend of gains in health. Globally, those most vulnerable to these effects are poorer countries and poorer populations.

Reducing greenhouse gas (GHG) emissions (mitigation) will, in the long term, reduce the magnitude of global climate change and, if adequately targeted, can reduce local co-pollutants that worsen short-term health outcomes. But projections indicate that the world is already locked into a two-degree centigrade warmer climate, which is expected to have negative health effects. Minimizing these effects will require institutional, behavioral, built environment, etc., adjustments (adaptation). Therefore, minimizing the health impacts of climate change and CO_2 co-pollutants requires both adaptation and mitigation.

Some global trends add to the complexity in taking action. These include rapid and unplanned urbanization, aging populations, and rising energy demand from a growing population. Other global trends, however, can facilitate mitigation efforts and boost population resilience. These include increased literacy, improvements in health service coverage, and technological innovations in infrastructure engineering, medical prevention diagnosis and treatment, renewable energies, remote sensing, and disaster preparedness. In climate change and in other areas, development can have positive as well as negative effects on vulnerable populations. Environmentally sustainable and well targeted measures (i.e., pro-poor and covering the most vulnerable populations) can ensure positive net final outcomes.

Adaptation

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "the process of adjustment to actual or expected climate and its effects." In the case of health, the purpose of the adjustments is to avoid harm or exploit beneficial opportunities to improve health outcomes. Climate change effects on health outcomes are mediated through multiple environmental, social and public health factors. Effective adaptation measures to reduce both the current and future estimated additional burden of disease are equally complex, requiring structural, behavioral and technological changes that are well targeted and cost-effective across several sectors and administrative levels. In most cases, such measures reduce the burden of disease due to both climate- and non-climate-sensitive diseases. General improvements in infrastructure and interventions to improve health in general can also reduce the burden of disease due to climate change.

WHO estimates that climate change may add as much as US$2–4 billion in annual health sector costs by 2030. International funding for health adaptation to safeguard against these costs, by contrast, would be less than 1 percent of this figure (WHO Euro, 2013). World Bank financing could therefore have a significant impact and result in long-term cost savings.

The value of adaptation is clear. Whether in infectious disease, heat waves or natural disasters, history has proven that preparedness and response to threats can greatly limit the losses to health, human life and economies. For example, in 1970 a Category 3 hurricane hit East Pakistan (present day Bangladesh) resulting in 500,000 deaths. Similar storms hit in 1991 and 2007, causing 140,000 and 3,400 deaths, respectively. Collaborative adaptation over the intervening decades led to these dramatic improvements in lives lost (Smith et al., 2014) by increasing Bangladesh resilience to natural disasters.

The academic health and climate literature has classified adaptation measures and options in multiple ways including:

- Incremental, transitional, and fundamental actions: according to the depth of the change, measures can be incremental when they imply simply increasing the frequency or quantity of existing interventions that may or may consider climate change. Changes are said to be transitional if they deliberately take into consideration climate change and expected health outcomes due to climate change. Fundamental is change that is classified as transformational and permanent.
- Short- versus long-term measures.
- Proactive versus reactive measures: proactive measures are taken to prevent events that have not happened yet but for which there exists a risk; reactive measures address events that have already happened and are likely to recur with greater or lesser intensity.
- "No regrets," "low regrets" and win-win solutions: in terms of cost-benefit, "no-regrets" adaptation measures are those whose socioeconomic benefits exceed their costs, regardless of what happens to the climate. Measures are considered "low-regrets" when the associated costs are somewhat low and the benefits are expected to be large if the projected climate change occurs. Win-win options are those that minimize social risk and/or exploit potential opportunities and also have other socioeconomic or environmental benefits.
- Local and general actions: in terms of geographical scope, measures can be local (such as vector control in an area), or general/systemic.
- Sector-specific or broader: adaptation measures may be taken either in the health sector or in other sectors.

Using vector control as an illustration, the length of an insecticide-spraying, mosquito-control campaign could be increased to account for higher rainfall. This would be an incremental, reactive, short-term, local, and—in some areas—win-win measure if it also reduces dengue, or eastern equine zoonosis in horses. Generally, this would be a health sector-implemented measure. Before the rainy season starts, the same intervention may be modified taking into consideration climate change projections suggesting that temperature and humidity changes could expand the breeding areas for the malaria-transmitting mosquitoes. This adjustment would make the measure transitional, proactive, short-term, local, and (depending on its costs and other factors) either low-regrets or win-win. Alternatively, a new technology such as a vaccine or genetic modification of the vector to prevent disease transmission, applied across the world, would be transformational, proactive, long term, general, and potentially no-regrets.

Adaptation is country-, place- and context-specific, and no single approach to reduce the actual or expected climate effects will be appropriate everywhere. However, countries identified as climate "impact" hotspots for health outcomes in this paper share some commonalities that could guide a general adaptation approach. For the most part, these countries have high prevalence of climate-sensitive diseases, or are by dint of their geographic location at high risk of suffering from climate-related natural disasters such as floods and heat waves, while also having weak health systems and being at an early stage of economic development.

We have modified the approaches for managing the risks of climate change from the most recent report of the IPCC Working Group II to reflect the characteristics of the "impact" hotspots and the health focus. For these countries, reducing current vulnerability and exposure to climate and climate variability is not just a first step but at the core of adaptation efforts to counter the negative impact of climate change in health outcomes. Regarding health sector-specific interventions, the World Bank focuses on supporting countries who accelerate the achievement of universal health coverage[6] (UHC). For the World Bank, accelerating country's progress towards UHC requires a combination of not only increased access to service and financial protection, but also to work across sectors to achieve HNP outcomes (examples provided in Annex 4). This last aspect focuses on public health-enhancing measures that fall outside the purview of the health sector. Climate-smart measures in non-HNP sectors are an important element for achieving UHC, and include issues such as access to energy and clean water.

Most interventions, whether implemented in health or other sectors, could be integrated across the Bank's policy dialogues and economic analyses and/or be supported through World Bank investments. In many cases, The Bank could improve the impact of its development work by including climate-sensitive health outcomes while considering adaptation measures across non-health sectors. By ensuring that climate change issues are considered

6 UHC is defined by World Bank and WHO as: "everyone—irrespective of their ability to pay—gets the health services they need in a timely fashion without undue financial hardship as a result of receiving them." (World Bank/WHO 2014).

within its universal health care strategy, the Bank could ensure that this approach to the health sector both maximizes health outcomes and makes them as sustainable as possible.

Mitigation

Beyond air quality, other actions to address the emissions that drive climate change can affect health in more moderate ways.[7] Given that actions to address the key drivers of climate change can influence important determinants of health, we describe the relationship between these drivers and various components of the burden of disease, present the geographic patterns of that burden, and discuss how it could be reduced in response to various mitigation pathways being discussed.

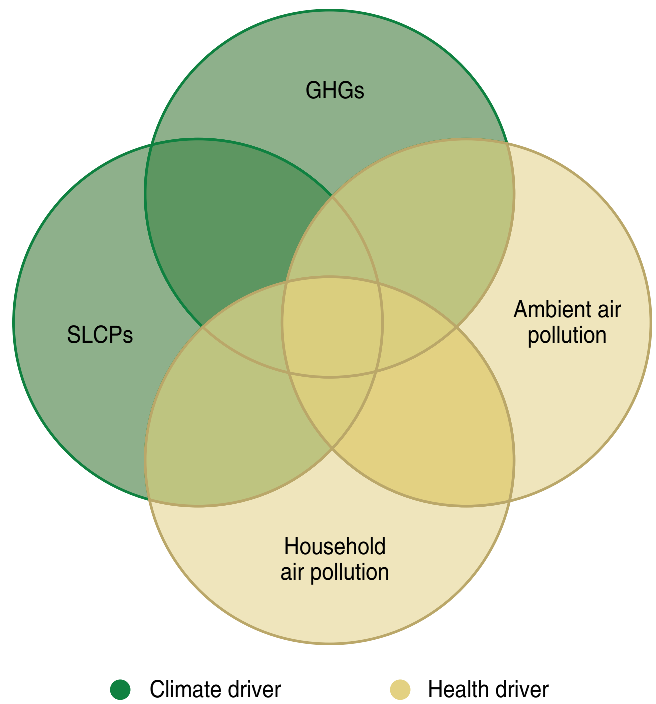
Unlike the climate-health impacts discussed in the prior section that lend themselves to adaptive responses, the health effects of air pollution are more directly linked to mitigation responses (although some future adaptive measures may still be needed to deal with extreme air quality conditions associated with natural emissions such as wildfire, pollen, or mineral dust).

Nevertheless, as stated in the Introduction, the objective of this work is to identify the geographic areas where a change in burden of disease is anticipated as a result of climate impacts or changes in the drivers of climate change. Sector-specific guidance notes will focus more on the proposed adaptive and mitigation responses to the climate-health threats identified and assessed in this work.

Appropriate operational strategies will hinge upon the recognition that some co-emitted types of airborne pollution may not have a climate impact but will still have a strong health impact. Immediate threats from air pollution can be prioritized now while health services prepare for new threats that are expected to emerge over time that require adaptive strategies. Additionally, health impact analyses must consider changes in health risk factors associated with the mitigation activities themselves, for those mitigation actions that may have non-air quality health benefits.

The schematic shown in Figure 4.1 attempts to demonstrate the complexity of this situation. The targets of the present analysis are those sources with emissions that both drive climate and lead to direct health impacts. It illustrates that pollution is not neatly defined—in terms of either emission sources or pollutants—with respect to categorization. Some emissions contribute to climate change—either in the long- or the short-term—and others contribute to health impacts via exposure in or near the home or in the ambient atmosphere. Many of these pollutants are common to two or more categories and many sources contribute to multiple impacts; the reduction of these sources therefore can lead to multiple benefits.

Figure 4.1: Drivers of climate change and environmental health.



For current purposes, we present a more detailed typology of various atmospheric pollutants with a focus on health effects that result from degraded air quality, principally due to fine particles and ground-level ozone. Globally, fine particulate matter is responsible for more than 95 percent of deaths due to ambient air pollution; however, ground-level ozone is a significant source of chronic obstructive pulmonary disease and other health complications (WHO, 2009; Lim, 2012; US EPA, 2013). The typology presented in Annex A is stratified by the timescales across which they impact the climate system, and we review the health impacts and important co-emitted species of each category, noting other impacts of these co-emitted species where important.

Based on these general observations, it is clear that some countries would benefit from climate and health interventions

7 It is also important to note that some drivers of climate change (or mitigation strategies) may have an effect on health that is not mediated through air quality (e.g., chlorofluorocarbons and some hydrofluorocarbons may increase risk of skin cancers through stratospheric ozone depletion; active transportation strategies yield health benefits by reducing emissions, but also by improving cardiovascular health through exercise; reduced deforestation can ameliorate malaria spread, climate smart agriculture can reduce emissions while increasing productivity and improving nutrition, etc.).

that focus on emission reduction strategies that target the common sources of both greenhouse gas emissions and ambient air pollution. Others would benefit—to a greater degree—from strategies that focus on short-lived climate pollutants and household air pollution (while ensuring that such strategies are consistent with long-term net carbon neutrality). In Annex C, we explore the statistics in more detail to identify countries that are experiencing the greatest rates of disease (as opposed to overall burden) stemming from each type of air pollution.

These lists provide an important starting point for disentangling the individual climate and health risks facing each nation, but a careful analysis at the national level that examines the common sources of greenhouse gases, short-lived climate pollutants and other air pollutants (along the lines of the global analysis conducted by Rogelj et al., 2014)—is needed to fully understand optimal strategies for addressing climate and health risks simultaneously. It is clear, however, that in the absence of such an analysis those countries appearing near the top of the lists presented in Annexes B and C offer clear opportunities for climate and health interventions spanning a wide range of pollutants, with multiple benefits.

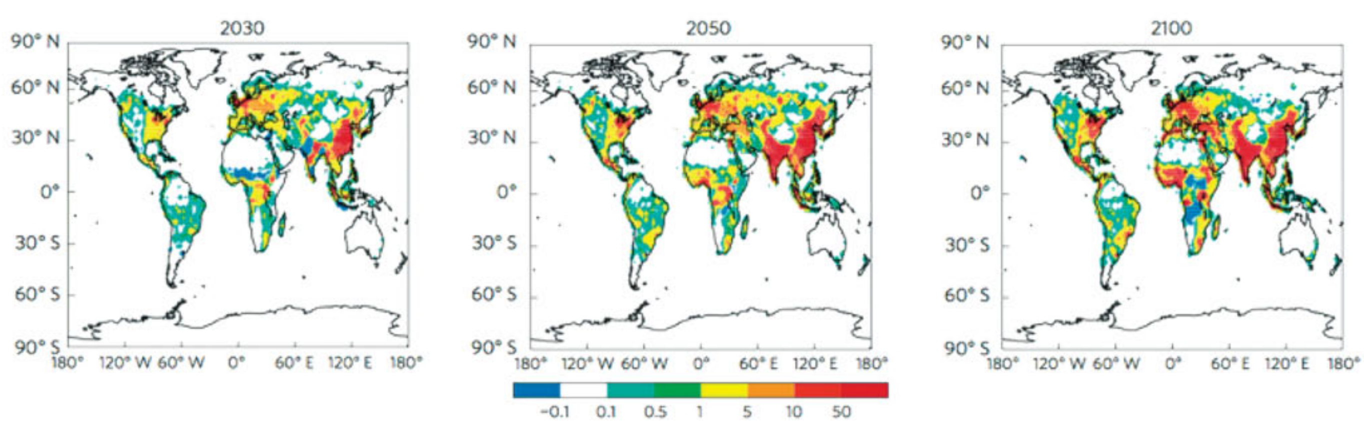
Geographic Analysis of Potential Reduction in Air-Pollution Health Impacts

Various efforts have documented the health impacts of climate change—and therefore the health benefits of climate mitigation—but most prominently the IPCC (Smith et al., 2014). The geographic range of these benefits has already been assessed under the adaptation sections of this report. However, the health benefits of air quality or other health risk reduction that accompanies mitigation of greenhouse gases and short-lived climate pollutants will have different geographical features relative to these generalized climate change impacts.

As noted earlier, several studies have examined the "co-benefits" of climate mitigation associated with improvements in ambient air quality. Figure 4.2 shows results from one of these analyses using state-of-the-science atmospheric models and new relationships between chronic mortality and exposure to fine particulate matter (West et al., 2013). As noted within that study, the overall level of health benefit depends on the scenario choice modeled and, in particular, the assumed level of air pollution control in the counterfactual scenario and technology choice in the abatement scenario. They find that greenhouse gas abatement consistent with the Representative Concentration Pathway 4.5 (RCP4.5) scenario avoids 0.5 ± 0.2, 1.3 ± 0.5 and 2.2 ± 0.8 million premature deaths in 2030, 2050 and 2100, respectively. The greatest benefits occur where air pollution is currently worse, in **South** and **East Asia,** followed by the **Eastern U.S., Central Europe,** and parts of **West** and **Central Africa,** and **Central America.**

Similarly (UNEP/WHO, 2011) assessed the health benefits of undertaking key measures to reduce black carbon and methane and determined that more than 2.4 million lives could be saved each year by 2030 through air quality improvements associated with interventions to curb short-lived climate pollutants. Importantly, these analyses assessed only those health benefits attributable to reduced *ambient* air pollution, despite the fact that several of the key measures would likely reduce household exposure as well. This work was refined and repeated in 2013 (World Bank/ICCI, 2013) using updated inventories and examining the 14 measures

Figure 4.2: Avoided premature mortality from $PM_{2.5}$ (cardio-pulmonary disease plus lung cancer) and ozone (respiratory) in 2030, 2050 and 2100 (deaths per year per 1,000 km², color scale). Co-benefits are presented for the specific reference and greenhouse gas abatement scenarios modeled in West et al. (2013).



individually. Results from this re-analysis confirmed that ambient air pollution benefits would be large but arrived at a somewhat lower total of approximately 2.2 million premature deaths avoided annually (i.e., the average of two models).

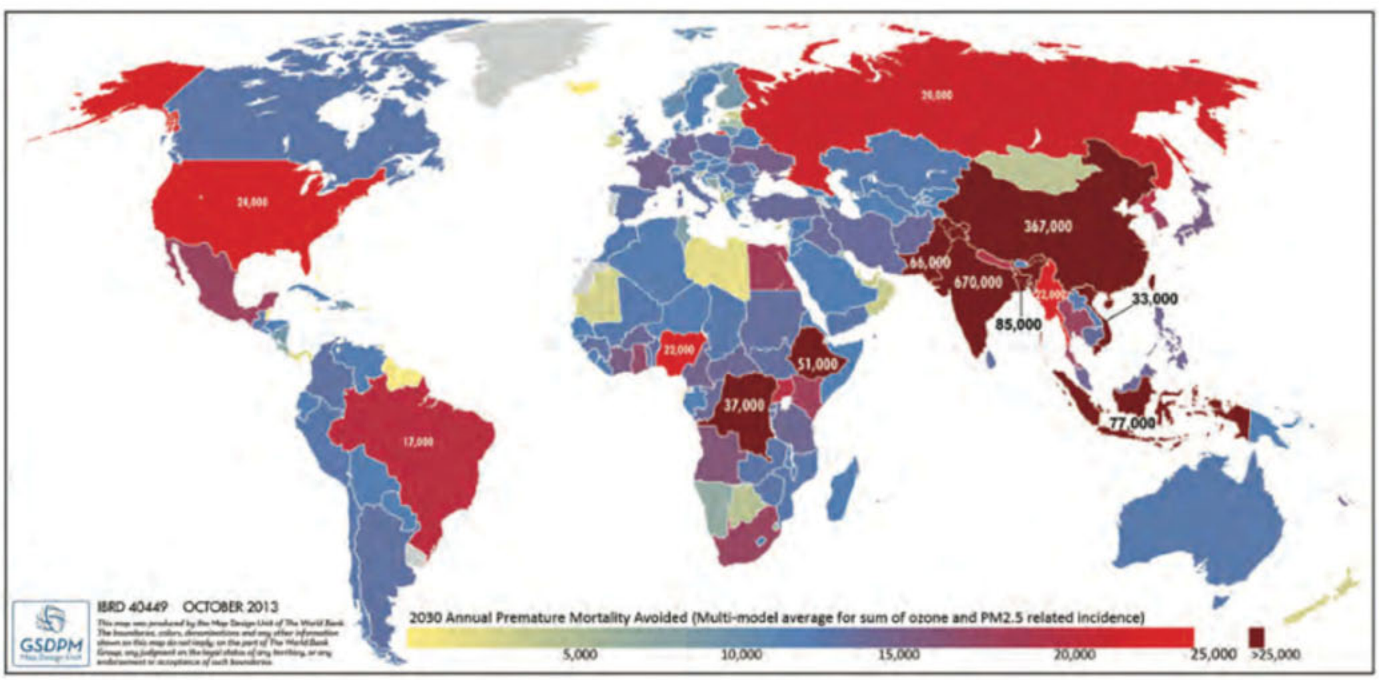
Figure 4.2 presents the geographical distribution of avoided premature mortality that could be achieved in 2030, with full global implementation of 14 measures that address the most significant sources of black carbon and methane (World Bank/ICCI, 2013). **India, China, Pakistan,** and **Indonesia** stand out. In Africa, **Kenya** and **Democratic Republic of Congo** would stand to benefit from the full suite of measures targeting short-lived climate pollutants. It should be noted that this is relative to a zero CO_2 mitigation reference scenario, so these are upper estimates of what could be achieved with this kind of mitigation alone but lower estimates of what could be achieved through the combined mitigation of short-lived pollutants and CO_2 simultaneously. Because these results are integrated within national borders, the larger, more populous countries stand out. Taken together, Figure 4.2 and 4.3 confirm that regions that are currently experiencing the greatest public health burden associated with air pollution are the same to benefit the most from efforts to reduce it.

Multiple Benefits of Mitigation

Health will be significantly affected by our changing climate and these changes are driven by the emission of greenhouse gases as well as short-lived climate pollutants. However, detailed examination of mitigation scenarios has revealed that reducing these health impacts is just one of many reasons to reduce harmful emissions to the atmosphere.

Several studies have confirmed large anticipated air quality-related health benefits that would accrue at various levels of carbon mitigation (Nemet et al., 2010; Hamilton et al., 2014; Parry et al., 2014; West et al., 2013; Thompson et al., 2014). A smaller number have considered other benefits that would accompany large-scale emissions reductions, such as energy savings and energy security, net employment and/or other economic benefits and avoided crop losses and other ecosystem services (IEA, 2014; New Climate Economy, 2014; World Bank/ClimateWorks, 2014; New Climate Institute, 2015; Driscoll et al., 2014). Even fewer assess the direct benefits of avoided climate change alongside the multiple benefits that could accompany mitigation actions with self-consistent discounting and monetization procedures across

Figure 4.3: Health benefits of 14 key black carbon and methane interventions. Regional distribution of avoided premature mortality in 2030 as estimated by the BenMAP tool for all $PM_{2.5}$ and ozone impacts, with all measures combined (including the fan-assisted cookstove measure and the 50-percent reduction in global fire measure).



Source: World Bank/ICCI (2013).

the different categories of benefits (e.g., few studies quantify the costs and benefits of impacts attributable to different pollutants as a time series, thereby differentiating pollutants with near-term versus long-term effects, and then apply a consistent social discount rate to both the impacts and the valuation of costs as they are incurred (Shindell, 2015)).

These large and immediate benefits of mitigation action on air quality and health notwithstanding, it is important to recognize the full social value that accrues with low-emission development. All benefits (e.g., energy and food security, net employment benefits and other economic benefits, ecosystem services and other environmental benefits, etc.) should be quantified where feasible but acknowledged where quantification is not possible (World Bank/ClimateWorks, 2014). Some mitigation actions yield health benefits that are unrelated to air quality improvements (such as active transportation, reduced deforestation, etc. (Patz et al., 2014; Garg 2015)). Given the focus of the present analysis on linkages to human health benefits, results presented here are focused solely on identifying geographical regions where the health benefits can be realized, while acknowledging that additional social value is likely to accrue both within these same regions as well as globally.

Conclusion

The drivers of climate change and co-emitted pollutants[8] have significant impact on both the health of humans and the planet.

This paper is an attempt to identify the geographies and people within that are most vulnerable to the health impacts of these climate co-pollutants as well as the impacts of climate change. The paper also links these impacts to country readiness to improve resilience in an attempt to tie these physical functions to sociological response. This analysis of hotspots provides the foundation for developing better responses and provides a guide for these geographies and countries that face the highest burden of impact so that they can confront them in ways that are cost-effective and scalable.

These data can be used to prioritize both countries and types of interventions. Following the results of this paper, a next step might be to perform a more detailed diagnosis of the causes and sources of the climate-sensitive health impacts. Better understanding of vulnerability can inform systematic country diagnostics, country partnership frameworks, and other relevant operations under preparation. Tailoring relevant projects—chiefly in health, nutrition, and population (HNP), but also in sectors that have direct impacts on HNP outcomes—can ensure that climate-health considerations are woven into economic analysis and project design.

Some tools exist and others are under development to support team efforts and minimize their burden; for instance, two operational guidance notes to guide health sector interventions are in progress. The Climate Change Cross-Cutting Solutions Group can provide technical support to HNP teams to carry out climate and health vulnerability assessments and the design of interventions, such as climate services for health, early warning systems, climate smart surveillance systems, "greening" the health sector, and preparing requests for climate funds.

The Cross-Cutting Solutions Group is also developing a programmatic approach to efficient, clean cooking and heating that can significantly reduce household air pollution, including black carbon. This is in addition to developing new operational tools that will help municipal administrations to understand the potential air quality and health benefits of actions that are within their authority. Moreover, additional analysis can better identify operational strategies to maximize development benefits tailored for countries suffering from ambient air pollution, household air pollution, or both. These steps to curb emissions have the dual benefits of saving lives now and contributing to climate change mitigation, thereby reducing impacts on health in the future.

In general, this paper should be taken as an entry-point for furthering dialogue with countries and regions to improve understanding and action on climate change and health. There are an increasing number of tools available for making most appropriate climate changes and health interventions, and it is expected that we will work further to improve and enhance this chest of resources moving forward. It is important that World Bank staff and others working in development become aware of these challenges and opportunities so that we might collectively—and simultaneously—improve climate, health, and overall development outcomes.

8 Climate drivers that affect health outcomes include fine particulate matter (including black carbon which is a strong warming agent and other components of aerosol particulate that may offset a portion of that warming) and methane, which contributes to the formation of ground-level ozone or smog.

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ANNEX

A Typology of Pollutants That Drive Climate Change, Health Impacts, or Both

Carbon Dioxide and Long-Lived Greenhouse Gases

The chief driver of climate change is unquestionably carbon dioxide (CO_2) due to its long atmospheric lifetime and its key role in stabilizing the climate system at a habitable temperature. Human activities have altered the global carbon cycle causing a rise in ambient concentrations of CO_2 and upsetting a balance that has been in place for centuries. Based on the latest observations, a 7.5 percent increase in radiative forcing from greenhouse gases (GHGs) occurred between 2005 and 2011 alone, with CO_2 contributing 80 percent toward this increase (Hartmann et al., 2013). Long-term climate stabilization cannot be achieved without large and rapid reductions of CO_2 emission that achieve net zero carbon emissions in the latter half of this century (World Bank, 2014).

The sources of CO_2 are numerous and include virtually all forms of combustion spanning our energy system, as well as a few other sources such as the calcination reaction in cement production (Fischedick, et al., 2014). While CO_2 itself is not toxic to humans at ambient concentrations, it is almost never emitted alone. Rather, a wide variety of co-emitted pollutants constituting a large majority of global air pollution accompany the release of CO_2 from various combustion sources. The variation in sources tracks the variation in co-emitted pollution and, therefore, the variation in health impacts.

Nitrogen oxides (NO_X), sulfur dioxide (SO_2), mercury and other heavy metals accompany the CO_2 emitted from fossil-fuel power generating facilities. These co-emitted pollutants vary considerably in terms of their emission rate depending on the fuel type and the degree of post-combustion control technology in use at individual generating units. These pollutants play a significant role in the secondary formation of particulate matter ($PM_{2.5}$) and contribute to the regional transport and formation of ground-level ozone (WMO/IGAC, 2012).

Transportation sources (cars, trucks, buses, aircraft), residential and commercial buildings, and industrial sources also are collectively significant sources of CO_2 while emitting NO_X, SO_2, volatile organic compounds (VOC) and carbon monoxide (CO), which is subsequently oxidized to become CO_2, and other precursors to fine particulate matter and ground-level ozone.

Short-Lived Climate Pollutants (SLCPs)

SLCPs, such as black carbon (BC), methane (CH_4), ground-level ozone (O_3), and many hydrofluorocarbons (HFCs), have a warming effect on climate, and most of them are also dangerous air pollutants with detrimental impacts on human health, agriculture and ecosystems (CCAC, 2013). The rapid reduction of black carbon emissions along with co-emitted components of particulate matter could avert approximately 0.18–0.19°C of warming by 2050 (Rogelj et al., 2014; Shindell et al., 2012). Interventions that address methane could yield a similar climate benefit with combined temperature reductions of black carbon and methane estimated at 0.4–0.5°C in 2050 (UNEP, 2011a; World Bank/ICCI, 2013). Recent studies estimate that replacing high-Global Warming Potential (GWP) HFCs with low-GWP alternatives could avoid an additional 0.1°C of warming by 2050 (Xu Y. et al., 2013).

In total, SLCPs could avoid more than half a degree of temperature rise over the next several decades while climate adaptation measures are being deployed and implemented, extending and improving the quality of lives. It is important to point out that—precisely because of the significant overlap in sources that emit both CO_2 and SLCPs—the degree of avoided warming through SLCP measures alone is strongly dependent on the rate of coincident carbon mitigation (Rogelj et al., 2014).

Several sectors have black carbon-rich sources that emit varying amounts of black carbon along with several other co-emitted air pollutants including: agriculture-related open burning, residential energy, transportation, industry (especially brick kilns), and oil and gas flaring. Black carbon is only one component of primary $PM_{2.5}$ and typically makes up less than 10 percent of ambient $PM_{2.5}$ mass (Bond et al., 2013), but can constitute much higher fractions for specific sources such as diesel particulate emissions. Diesel particulate emissions can be up to 80 percent black carbon by weight for older vehicles (Bond et al., 2007, World Bank/ICCT, 2014).

The residential sector bears special mention due to the proportionately high burden of disease attributable to black carbon and co-emitted $PM_{2.5}$ from this sector. It is the second largest source of black carbon emissions, primarily linked with the residential burning of biomass, but also other solid fuels, for cooking and heating. Some 3 billion people in the developing world—representing nearly half the world's population—burn solid fuels such as wood, dung, coal, charcoal and crop residues in traditional stoves and open fires for these purposes (U.S. EPA, 2012). The World Health Organization (WHO, 2014a) estimates that 4.3 million deaths a year worldwide are attributed to diseases associated with cooking and heating with solid fuels. This includes household exposure to cooking smoke as well as the contribution of this smoke to ambient pollution outside the home. In 2010, household cooking with solid fuels accounted for 12 percent of ambient $PM_{2.5}$ globally, varying from zero percent in five high-income regions to 37 percent (2.8 μg/m^3 of 6.9 μg/m^3 total) in southern Sub-Saharan Africa (Chafe et al., 2014). In fact, pollution from cooking kills more men, women, and children than AIDS, malaria, and tuberculosis combined. In addition to these premature deaths, millions more are sickened from acute and chronic lung and heart diseases while hundreds of thousands more suffer burns or disfigurement from open flames and dangerous cookstoves.

Methane has indirect impacts on human health and ecosystems, including agricultural production, through its role as the primary precursor of ground-level ozone (CCAC, 2013). Ozone air pollution has been estimated to cause around 150,000 deaths annually worldwide and affects the health of many more (Lim et al., 2012).

Ozone near the surface in the lower atmosphere is harmful to human health and ecosystems due to its ability to oxidize biological tissue. A common human health impact of ground-level ozone is respiratory illnesses such as asthma in children (WMO/IGAC, 2012). It also damages ecosystem structure and functions and the health and productivity of crops, thus threatening food security. Ozone also reduces the ability of plants to absorb CO_2, altering their growth and variety and threatening food security and malnutrition in the case of staple crops.

While HFCs emissions are currently small, they are projected to rise and could be equivalent to 7 to 19 percent of CO_2 emissions by 2050 (UNEP 2011b); however, they do not have adverse air quality-related health effects similar to black carbon, methane or ozone.

Co-Emitted Air Pollutants with Air Quality/Health Impacts

In addition to greenhouse gases and SLCPs, there are a variety of other common air pollutants that originate from common sources as the many drivers of climate change discussed above. In particular, the precursor pollutants that aid in secondary formation of fine particulate and ground-level ozone (i.e., sulfur dioxide, nitrogen oxides, non-methane VOCs, etc.) do not typically result in direct health impacts at their regulated levels observed in most parts of the world, but their co-emission is responsible for the bulk of the adverse public health exposure to air quality. This result is explained by the fact that the majority of $PM_{2.5}$ mass is typically comprised of secondary sulfate, nitrate or organic material (and, unlike black carbon, these components of particulate matter do not drive climate change; in fact, they mostly act to offset global warming by reflecting some degree of solar radiation back to space). Methane aids the increase of global background concentrations of ground-level ozone, but contributes a far smaller proportion of the observed peak (urban) ground-level ozone exposure that leads to the majority of severe health effects. Peak urban concentrations are a combination of local emissions of NO_X and non-methane VOC combining with regionally transported precursors and global background ozone (WMO/IGAC, 2012).

Finally, mercury, benzene, dioxin and a variety of other air toxics are released via different combustion processes related to many of the sources listed previously. While these pollutants do not have a direct role in altering the climate in the near-term or over the long-term, they have a significant effect on health (U.S. EPA, 1998).

ANNEX

B

Geographic Analysis of Climate Drivers

Greenhouse gas emissions serve as an excellent basis for identifying hotspots that reflect the drivers of climate change. Table B.1 presents national emissions of greenhouse gas (GHG) emissions expressed as CO_2 equivalent or CO_2e (sorted two ways). However, these lists are a relatively poor indicator of the geographical specificity of the health impacts given that the drivers of health impacts are the co-emitted pollutants that accompany emission of GHGs rather than the GHGs themselves. This imperfect alignment between GHGs versus traditional air pollutants (fine particles and ground-level ozone) limits the analysis presented here. For example, the degree of overlap between climate and health drivers will differ significantly by national circumstance. **China, U.S., India, Russia,** and **Japan** top the list of GHG emitters and clearly are the focus of carbon mitigation efforts. However, with respect to health impacts of co-emitted air pollution, these countries are at very different stages of addressing their air quality concerns.

Table B.2 presents similar data on greenhouse gas emissions, but it presents the top 10 GHG emitters within various income brackets sorted by gross national income per capita. Countries at the top of these lists will have lower economic efficiency per unit of GHG emissions (alternatively, these countries could be described as having a relatively higher GHG intensity per unit of GDP). This often is correlated with less efficient combustion and greater health impacts, but also will result in less direct association with the determinants of health most directly associated with mitigation activities discussed in the main text.

A second way to examine the same data is by income bracket. The second list also presents to top GHG emitters (expressed in CO_2e) but presents only the top 10 emitters for each income bracket based on the World Bank fiscal year 2015 income classifications (high income with annual per capita GNI ≥ US$12,746; upper-middle income: US$4,125–12,745, lower-middle income: US$1,046–4,125, and lower-income ≤ US$1,045).

Table B.1: Climate driver mapping, based on carbon. The data below are taken from the World Bank World Development Indicators database (data.worldbank.org) and include country-level data for the top carbon emitters as of 2010. It presents all countries that emit more than 100 million metric tons (100,000 ktons) of carbon dioxide equivalent annually.

		2010 TOP CARBON EMITTERS (kTON (CO_2e))
All Income Levels	China	8,286,892
	United States	5,433,057
	India	2,008,823
	Russian Federation	1,740,776
	Japan	1,170,715
	Germany	745,384
	Iran, Islamic Rep.	571,612
	Korea, Rep.	567,567
	Canada	499,137
	United Kingdom	493,505
	Saudi Arabia	464,481
	South Africa	460,124
	Mexico	443,674
	Indonesia	433,989
	Brazil	419,754
	Italy	406,307
	Australia	373,081
	France	361,273
	Poland	317,254
	Ukraine	304,805
	Turkey	298,002
	Thailand	295,282
	Spain	269,675
	Kazakhstan	248,729
	Malaysia	216,804
	Egypt, Arab Rep.	204,776
	Venezuela, RB	201,747
	Netherlands	182,078
	Pakistan	161,396
	Vietnam	150,230
	Algeria	123,475
	Iraq	114,667
	Czech Republic	111,752
	Belgium	108,947
	Uzbekistan	104,443

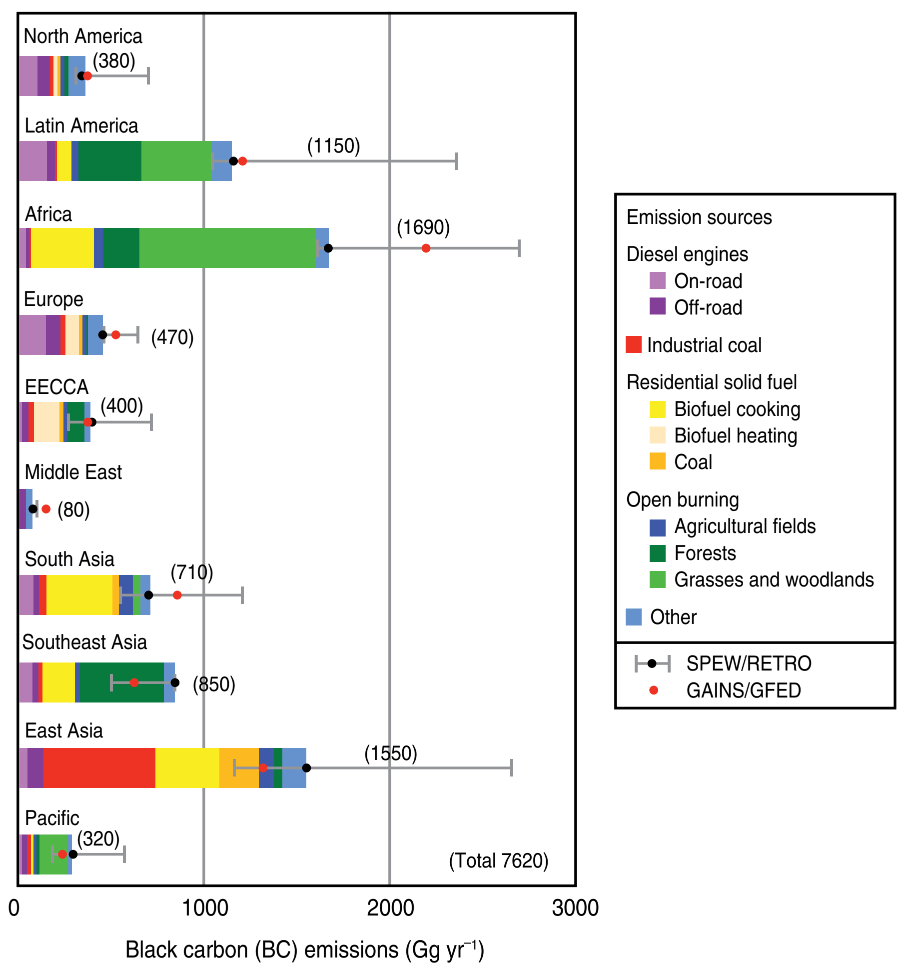
Table B.2: Top carbon emitters by income bracket.

INCOME BRACKETS BASED ON 2013 GNI PER CAPITA (ATLAS METHOD)		2010 TOP CARBON EMITTERS (kTON CO_2e)
Low Income	Bangladesh	56,153
	Zimbabwe	9,428
	Afghanistan	8,236
	Tanzania	6,846
	Ethiopia	6,494
	Benin	5,189
	Cambodia	4,180
	Uganda	3,784
	Nepal	3,755
	Congo, Dem. Rep.	3,040
Lower-Middle Income	India	2,008,823
	Indonesia	433,989
	Ukraine	304,805
	Egypt, Arab Rep.	204,776
	Pakistan	161,396
	Vietnam	150,230
	Uzbekistan	104,443
	Philippines	81,591
	Nigeria	78,910
	Morocco	50,608
Upper-Middle Income	China	8,286,892
	Iran, Islamic Rep.	571,612
	South Africa	460,124
	Mexico	443,674
	Brazil	419,754
	Turkey	298,002
	Thailand	295,282
	Kazakhstan	248,729
	Malaysia	216,804
	Venezuela, RB	201,747
High Income	United States	5,433,057
	Russian Federation	1,740,776
	Japan	1,170,715
	Germany	745,384
	Korea, Rep.	567,567
	Canada	499,137
	United Kingdom	493,505
	Saudi Arabia	464,481
	Italy	406,307
	Australia	373,081

The short-lived pollutants black carbon and methane are also drivers of climate change and may serve as a better geographical indicator of health impacts. Black carbon is most directly linked to local health impacts as a component of fine particulate pollution with direct health effects. Figure B.1 presents global emissions of black carbon by region that provides a basis for assessing where this pollutant is likely having its greatest impact on health. Clearly, the developing world is a large source of black carbon and the concentration of industrial and biofuel cooking sources in **South** and **East Asia** make this a likely candidate for significant health effects given what is known about the health impacts of these source categories.

Unlike CO_2, the climate impacts of black carbon are not distributed uniformly, and it will have the greatest warming effect close to where it is emitted. This is where the health impacts from direct exposure to fine particulate matter will occur as well. Figure B.2 (U.S. EPA, 2012) shows the geographical distribution of two key components of black carbon climate impacts (direct radiative forcing and cryosphere forcing). The radiative forcing (warming or cooling) related to cloud impacts is more uncertain and less understood. Again, **South** and **East Asia** show significant local forcing, but strong radiative forcing is apparent in **Africa** as well. Here it is important to point out the role of open burning in the black carbon climate forcing because the high organic carbon co-emitted through biomass combustion may offset some degree of this climate forcing, particularly in Africa. The greatest cryosphere forcing occurs near snow and ice where both black carbon and organic carbon are absorbing incoming solar energy relative to underlying snow which would reflect back to space in absence of the emissions.

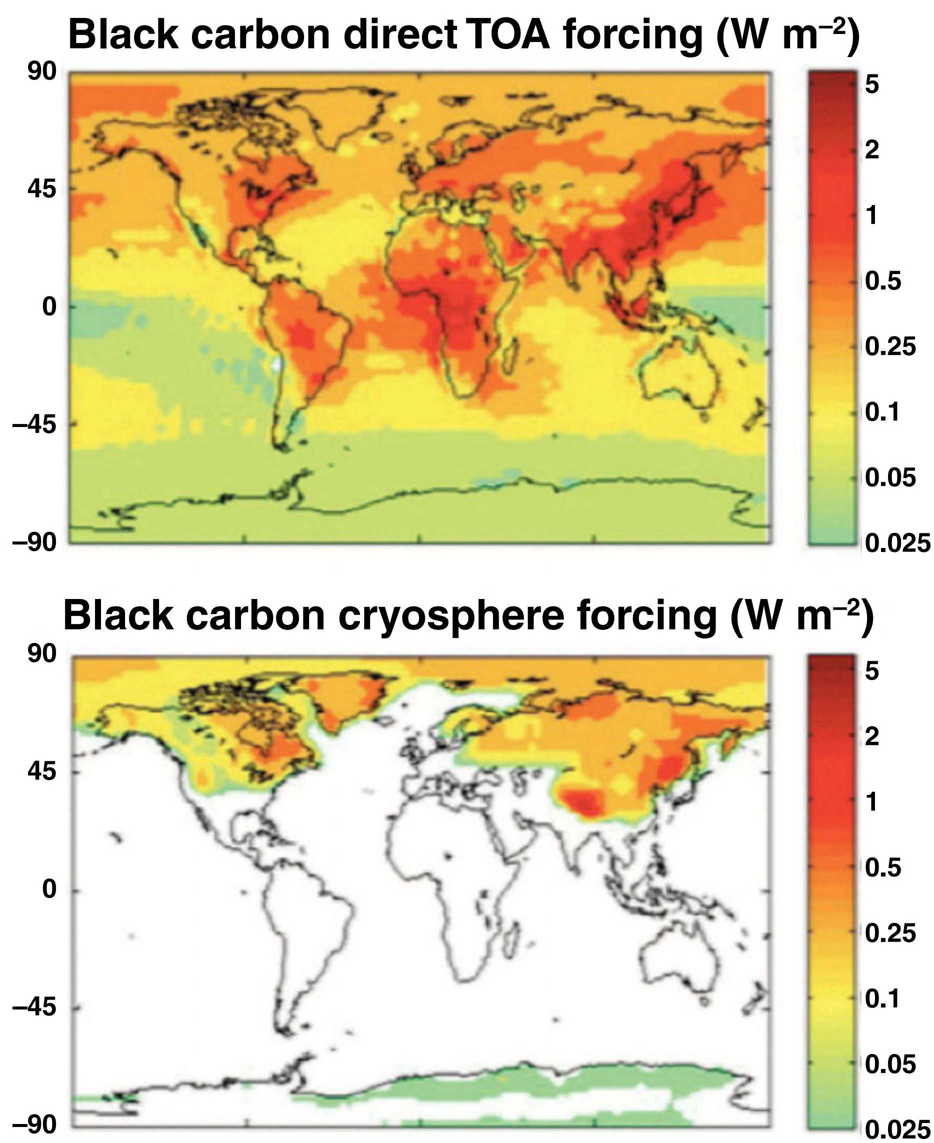
Figure B.1: Global emissions of black carbon estimated for 2000, (Bond et al., 2014). Totals are presented from two different emissions models (SPEW and GAINS) as reflected by the black and red dots.



The geographical influence of methane for both health and climate (and the climate influence of short-lived HFCs) is less region-specific and more global given the longer atmospheric lifetime relative to black carbon (several years versus several days). While the health impacts of ground-level ozone are normally quite local, the contribution of methane to ozone health impacts is through a shift in the global background concentration to which local air pollutants are added (analogous to the rising global sea level that contributes to higher local storm surges). This results in a methane effect that is global in nature whereas co-emitted NOx and VOC species contribute to local health impact.

In summary, this analysis demonstrates that the drivers of climate change have geographical patterns that are identified in the main text, but are less direct means of establishing areas that will enjoy the greatest health benefits of mitigation action. For that, metrics explored in the main text and Annex C provide a more direct relationship between mitigation opportunities and health benefits.

Figure B.2: Direct radiative forcing as measured from the top of atmosphere (TOA) and cryosphere forcing due to black carbon (U.S. EPA, 2012).



ANNEX

C

Health Driver Mapping Based on Burden of Disease

The data below are taken from 2013 Global Burden of Disease analysis performed by the Institute of Health Metrics and Evaluation and the Health Effects Institute (IHME, 2015). Both tables present the population normalized burdens of disease (in terms of disability adjusted life-years, or DALYs) attributable to ambient air pollution (AAP, in second column) and household air pollution (HAP, third column) in 2013 (fine particulate pollution only). Only countries with levels greater than one standard deviation above the median value of all countries appear in the table. The left table is ranked by AAP and the right table by HAP. Shaded rows indicate countries that lie more than one standard deviation (yellow), two standard deviations (orange) or three standard deviations above the median value in *both* lists.

Table C.1: National (normalized) burden of disease statistics attributed to AAP (left) and HAP (right; DALYs per 10,000 for 2013, IHME, 2015).

COUNTRY	AAP DALYs PER 100,000	HAP DALYs PER 100,000
Turkmenistan	228.388051	1.11187139
Afghanistan	207.223582	308.847399
Belarus	191.695099	0
Chad	191.352904	375.649164
Ukraine	185.124223	0
Mali	168.284683	333.795889
Guinea-Bissau	167.259832	341.828408
Niger	158.968447	300.156773
Bulgaria	158.268407	0
North Korea	151.30028	290.113178
Georgia	151.034944	196.754213
Moldova	150.937578	0
Pakistan	146.881828	176.405974
Sierra Leone	144.486018	335.26503
Central African Republic	143.726699	357.632212
Mauritania	138.693702	147.169032
Russia	136.964143	0
Uzbekistan	136.439965	50.1864472
China	134.123987	113.164962
Guinea	133.863711	295.885737
Laos	133.37224	278.964656
Azerbaijan	131.891551	39.8601462
Kazakhstan	131.282442	47.2806374
Romania	130.235803	0
India	130.209485	198.520454
Montenegro	127.276907	0
Democratic Republic of the Congo	125.083904	324.669871
Burkina Faso	124.033842	252.951753
Hungary	122.991597	0
Myanmar	121.861776	242.389011
Nigeria	119.589077	206.818103
Bangladesh	119.138114	179.097708
Armenia	118.494999	32.5356619
Lithuania	117.673751	0
Cambodia	117.141596	259.70455
Cote d'Ivoire	114.680685	252.95423
Kyrgyzstan	114.050048	120.449526
Tajikistan	113.78175	115.684734
Cameroon	113.127537	246.701503
Macedonia	112.682453	0
The Gambia	111.983902	217.597183
Yemen	111.270068	68.1365278
Serbia	110.850459	0
Albania	110.240375	0
Latvia	109.864679	0
South Sudan	108.941111	327.12751

COUNTRY	AAP DALYs PER 100,000	HAP DALYs PER 100,000
Somalia	60.5118178	396.33399
Afghanistan	207.223582	380.847399
Chad	191.352904	375.649164
Central African Republic	143.726699	357.632212
Guinea-Bissau	167.259832	341.828408
Sierra Leone	144.486018	335.26503
Mali	168.284683	333.795889
South Sudan	108.941111	327.12751
Democratic Republic of the Congo	125.083904	324.669871
Niger	158.968447	300.156773
Guinea	133.863711	295.885737
Malawi	47.8550404	290.785126
North Korea	151.30028	290.113178
Madagascar	7.44873776	285.922488
Laos	133.37224	278.964656
Equatorial Guinea	70.8062025	278.11457
Papua New Guinea	11.8531166	274.684608
Cambodia	117.141596	259.70455
Cote d'Ivoire	114.680685	252.95423
Burkina Faso	124.033842	252.951753
Mongolia	39.106394	249.531494
Cameroon	113.127537	246.701503
Burundi	82.3558195	244.446268
Myanmar	121.861776	242.389011
Ethiopia	77.4468773	236.36928
Vanuatu	35.9112053	234.001744
Solomon Islands	1.93796679	229.829575
Lesotho	82.4978805	226.849705
Swaziland	72.4123257	225.3621043
Liberia	89.674168	223.09878
Tanzania	34.6186236	219.286747
Angola	82.1992498	217.887781
The Gambia	111.983902	217.597183
Togo	95.5500287	214.359994
Uganda	71.0824867	207.600994
Nigeria	119.589077	206.818103
Zambia	57.762024	201.836004
Congo	75.5663931	199.175204
India	130.209485	198.520454
Georgia	151.034944	196.754213
Rwanda	65.2825362	196.216042
Mozambique	16.598487	189.542522
Haiti	67.9417166	189.261689
Kiribati	30.2672153	179.408348
Bangladesh	119.138114	179.097708
Eritrea	102.599388	178.308727
Pakistan	146.881828	176.405974
Benin	80.7686672	171.51407
Comoros	9.31425875	171.447129
Zimbabwe	38.7675456	166.936827
Kenya	39.947077	166.063523
Ghana	84.830794	165.329467
Timor-Leste	3.95407023	157.552039
Nepal	96.5253526	154.354269
Sudan	88.4549174	153.421977
Sao Tome and Principe	8.27023498	151.478872
Sri Lanka	67.7922612	151.016328
Mauritania	138.693702	147.169032
Philippines	37.8390512	146.2448

ANNEX

D

Adaptation Approaches to Manage Current and Projected Risks of Climate Change to Health

NON-HEALTH SECTOR EXAMPLES	HEALTH SECTOR EXAMPLES
Improved access to education, energy, safe housing, settlement structures and social support structures. Reduced gender inequality and marginalization.	Universal coverage of quality essential health and nutrition services, increased access to health facilities. Increased coverage of public health services such as vector control measures and surveillance.
Improved access to, and control, of local resources: land tenure, disaster risk reduction, social safety nets and social protection insurance.	Universal financial coverage for health services. Subsidies to increase demand for basic and preventive health services.
Income, asset and livelihood diversification, improved infrastructure; access to technology and decision making forums; increased decision making power; changed cropping, livestock and aquaculture practices; reliance on social networks.	
Early-warning systems; hazard and vulnerability mapping; diversifying water resources; improved drainage; floods and cyclones shelter; building codes & practices; storm and weather management; transport and road infrastructure improvements.	Climate-sensitive disease & morbidity surveillance & forecasting systems; heat waves, epidemics & emergency preparedness & response systems. Building codes & practices for health facilities, back-up systems in health facilities, resilient health services infrastructure and communication systems, alternative routes to health facilities; Air & water quality and temperature alert systems.
Maintaining wetlands & urban green spaces; coastal afforestation; watershed & reservoir management; reduction of other stressors on ecosystems and habitat fragmentation, maintenance of genetic biodiversity.	Vector and pests control and management by reduction/elimination of breeding sites.
Provision of adequate housing, infrastructure & services; managing development in flood prone and other high risk areas; urban planning and upgrading programs; land zoning laws; easement areas.	Locating new health facilities taking into consideration potential extended flood areas, alternative routes to reach health facilities, strategic situation of health facilities according to disaster preparedness and response plans.
Engineering and built environment options: sea walls, flood levees, & costal protection structures; water storage, improved drainage power plant & electricity grid adjustments.	Building codes and practices for health facilities, back-up systems in health facilities, resilient health services infrastructure and communication systems, alternative routes to health facilities, etc.

NON-HEALTH SECTOR EXAMPLES	HEALTH SECTOR EXAMPLES
Technology options: new crop and animal varieties, indigenous, traditional knowledge and methods, efficient irrigation, desalinization, food storage and preservation, hazard and vulnerability mapping and monitoring, early warning systems, building insulation.	Vaccines, development if new drugs; Climate-sensitive disease and morbidity forecasting and surveillance systems, health waves, epidemics & emergency preparedness & response systems. Climate adequate health infrastructure, to minimize the use of energy to maintain adequate temperature. Accelerated vaccine development, temperature stable diagnostic text, drugs & vaccines.
Ecosystems-based options: ecological restoration; soil conservation; afforestation & reforestation; mangrove conservation and replanting, assisted species migration and green infrastructure, control overfishing, seed banks, gene banks.	Natural & genetic vector control systems. Reduction of vector bleeding sites.
Services: social safety nets & social protection; food banks & distribution of food surplus; municipal services (water & sanitation).	Vaccination programs essential public health services including surveillance; enhanced emergency medical services.
Economic options: financial incentives; insurance; catastrophe bonds; payments for ecosystem services; pricing water to encourage universal provision and careful use.	Health insurance, including catastrophic health insurance.
Laws and regulations: land zoning laws, building standard and practices, easements, whether regulations.	Building codes, laws to encourage health insurance purchasing.
National & subnational government policies & programs: National and subnational adaptation plans.	Health system adaptation and disaster preparedness plans at all levels of health system linked to other sectoral adaptation & disaster plans.
Educational options awareness raising & integration into education gender equity in education, extension services sharing indigenous, traditional and local knowledge. Participatory action research.	Awareness raising of climate impacts & health emergency signs integrated in medical education & in health services to population and patients. Medical education includes emerging diseases.
Information options: hazard and vulnerability mapping; early warning & response system, systematic monitoring and remote sensing; climate services; participatory scenario development; integrated assessments.	Climate-sensitive disease and morbidity surveillance & forecasting systems linked to climate services, health waves, epidemics & emergency preparedness, & response systems. Air & water quality & temperature alert system.
Behavioral options: household preparation & evacuation planning; migration; soil and water conservation; storm and drain clearance ; livelihood diversification; changed cropping, livestock, & aquaculture practices.	Household awareness of actions in case of health alert or emergency, household knowledge of alternative routines to reach health facilities and health facility location and services provided in case of emergency.
Practical: social and technical innovations, behavioral skills, or institutional & managerial changes that produce substantial shift in outcomes.	Practical: Technical innovations in forecasting, prevention, diagnostic and treatment options.
Political: Political, social, cultural, & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation and sustainable development.	Political: political climate-smart decisions and investment for health system.
Personal: individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.	Personal: idem.

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