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Greenhouse Gas Emissions from Cities: Comparison of International Inventory Frameworks

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Abstract

Credibly and consistently reporting greenhouse gas (GHG) emissions from cities and urban areas enables policy makers and practitioners to contribute to addressing the challenge of climate change by meeting mitigation targets, and is critical to overall good municipal management. Good reporting allows for transparency, verification, and replication over time. This paper provides an understanding of the GHG emissions inventory protocols and methodologies as they apply to cities. Though the inventories generally use common terminology, the differences in inventorying approaches are many, and the implications of the inventorying results at the city-level are important to climate change policy and decision-makers. A compilation of GHG emissions inventory protocols is developed along with an analysis of their characteristics and inherent differences. Seven protocols are investigated: four are applied to Shanghai's community emissions; four to New York City's corporate emissions (i.e., those from municipal activities); and two to the reporting of Paris' emissions, including upstream components. The results show a significant degree of variability among the protocols.

Keywords

Community emissions; Corporate emissions; Life-cycle emissions; Shanghai; New York City; Paris

1. Introduction

Cities have a critical role in international efforts to reduce greenhouse gas (GHG) emissions. Recognizing the global significance of emissions, more than 160 countries have signed the Kyoto protocol, which pledges GHG emissions reductions of at least 5% by 2012 relative to 1990 levels, and by at least 50% by 2050 (UNFCCC, 2006). While nations may be the entities agreeing to treaties and setting targets, cities are where these changes will mainly occur – simply because cities are where the majority of people live. The world's population is now over 50% urban, and cities make an important contribution to national GHG emissions (Dodman, 2009; Kennedy et al., 2009; Sovacool and Brown, 2010; Hoornweg et al., 2010, 2011). Moreover, national-level policies are increasingly being supplemented with city-scale actions to mitigate climate change (Ramaswami et al., 2008). At the country-level, there exists a single GHG emissions inventory standard which has been developed by the Intergovernmental Panel on Climate Change (IPCC) and ratified by many countries. The IPCC has produced an internationally recognized standard inventory methodology for emissions from countries, and in turn countries are required to report their emissions through the United Nations Framework Convention on Climate Change (UNFCCC). At the city-level, city mayors, urban leaders, businesses and civil society all recognize the need to act to reduce the impacts of climate change on cities. Though there is no global, all-inclusive, harmonized protocol for quantifying GHG emissions attributable to cities and local regions, cities and their agencies have made several attempts at developing such standards and methodologies for inventorying GHG emissions. During the past 10 years, the number of organizations producing greenhouse gas inventories has increased, and a growing number of cities have recognized the importance of GHG emissions and are conducting inventories of their own. More than 6000 cities have proclaimed GHG emission reduction targets (Hoornweg et al., 2010).

A city's GHG emissions inventory is particularly valuable as the first step in a city's response to climate change. The inventory serves as an indicator of emission-intensive sectors, as well as providing verifiable metrics upon which to facilitate targeted climate-policies (Sugar, 2010). Though cities have a major role to play in reducing GHG emissions, climate change strategies for mitigation or adaptation cannot be set effectively to reach emissions reduction targets, if cities have not first created an inventory of GHG emissions for their activities.

Also of relevance, though often not included due to the complexities of quantification, are upstream and embodied emissions from energy use. By including upstream emissions from fuels, GHG emissions attributable to cities exceed those from direct end-use by up to 25% or more (Kennedy et al., 2009). Upstream and embodied emissions are challenging to incorporate, or may not even be reported, however, it does not mean they are less important for inventories. An inventory that reveals few emission components may still highlight areas of greater concern to the city, which still require strategic emission reduction targets and effective climate change policies.

Some studies have compared various local GHG emissions inventory tools and applications (Bader and Bleischwitz, 2009), though none have compared inventorying methodologies, including those aspiring to become international protocols. One methodology has been applied to a number of cities (Kennedy et al., 2009a, 2010) and has enabled an understanding of how and why emissions differ, resulting in an initiation of intercity learning. There are, however, no studies that have applied several institutionally recognized protocols to a single city to enable an understanding of methodological approaches to GHG emissions inventories, and the relevance and applicability of protocols. This paper aims to fill this gap, and demonstrates the importance of using benchmarks to assess the information captured in city-level GHG inventories.

The overall objective of this paper is to understand technical differences between international GHG inventory protocols for cities, with the expectation that this might lead to improvements and convergence in these protocols. To assist in demonstrating the significance of differences between protocols, we furthermore determine the GHG emissions inventories of cities using various GHG inventory protocols (The seven protocols assessed are listed in section 3 of this paper).

Following a review of city initiatives for measuring GHG emissions, this paper will proceed as follows:

- Section 3 provides a technical evaluation of community GHG emissions inventory protocols, highlighting their common criteria and inherent differences;
- Section 4 develops an awareness of the scale, complexity, and level of detail of GHG emissions inventories by applying, corporate-level protocols to New York City’s corporate GHG emissions, community-level protocols to Shanghai’s community GHG emissions, and upstream emissions for Paris’ community GHG emissions;

- Section 5 critiques the GHG emissions inventory protocols by analyzing the differences in cities' inventory results, assessing to what extent the protocols capture a comprehensive picture of city-level GHG emissions, and then pointing to a possible direction for harmonization of protocols.
- Section 6 provides recommendations for city managers.

2. Review of City Initiatives for Measuring GHG Emissions

Over the past two decades, several entities have been active in establishing methodologies for estimating urban GHG emissions (Kennedy et al., 2009b). One of the first organizations to undertake city-level GHG emissions reporting was the International Council for Local Environment Initiatives (ICLEI), which began in the early 1990s (now known as Local Governments for Sustainability). As part of the "Local Agenda 21" efforts, ICLEI initiated a campaign to quantify and reduce GHG emissions in cities. At that time, issues of boundary, emissions allocation, and methodological consistency across cities were topics of discussion in the academic literature (Harvey, 1993, Kates et al.. 1998). In the past ten years, the number of organizations producing GHG inventories for cities has increased, and methodological issues continue to be discussed. For example: the Greenhouse Gas Regional Inventory Protocol (GRIP) and the European Commission Covenant of Mayors (EC-CoM) were developed in Europe; GRIP looks at a regional scale, and EC-CoM has a major focus on energy. The WRI/WBCSD GHG Protocol has been designed for corporate reporting and separates emissions attribution into "scopes" that cover production and consumption, and the draft ISO 14064 provides standardized methodologies for corporate and project/product emissions inventories, both of which help to avoid "double counting." Bilan Carbone by ADEME is structured in a significantly different manner than the other protocols, encompasses upstream and embodied emissions, and as such produces a larger value for GHG emissions. An important gap clearly exists at the urban and sub-national level, and with urban greenhouse gas inventories now being conducted using differing methodologies and reporting schemes such as those compared in this paper, there is a growing need for harmonization.

A study by Bader and Bleischwitz (2009) compared six community-level GHG emission inventory tools. The study investigated differences between methodologies, online tools, and software to assist with emissions calculations. It then compared the interoperability of the tools with different reporting mechanisms. Our paper builds on that work as it compares details about the extent of the inventory analysis, the methodology used to make calculations, and how results are reported.

To cope with the problem of methodological variation between inventories, and the need for specific city inventories to facilitate climate finance; UNEP, UN-Habitat and the World Bank jointly developed the International Standard for Reporting Greenhouse Gases from Cities. A significant aspect of this framework is that it requires a city's GHG inventory methodology and results to be transparent, accessible, and available to everyone. A city's greenhouse gas inventory is particularly valuable as the first step in a city's response to climate change. The inventory serves as an indicator of particularly emission-intensive sectors, as well as providing verifiable metrics upon which to facilitate targeted project financing. As further actions on climate change are taken, methodologically consistent greenhouse gas inventories can indicate if the actions are reducing emissions as expected, or if their impacts are negated by unforeseen circumstances.

The most significant difference between GHG emission inventories for countries and cities is emissions attribution. For countries, inventories are based solely on production; that is, all emissions that are physically released within the spatial political boundary are counted (IPCC 2006).   However, the situation is more complex for cities, as they are sites of many in-flows and out-flows of goods and services. The vitality of cities depends on spatial relationships with surrounding hinterlands and global resource webs (Kennedy et al., 2007).   Inventories for cities require a combination of production- and consumption-based emissions attribution. While some emissions physically occur within the spatial political boundary (e.g. transport emissions, fossil fuel combustion for heating, etc.), some emissions that are released outside the boundary are a direct result of urban activities (e.g. electricity generation, waste decomposition). Further upstream GHG emissions are typically associated with key urban materials such as food, water, fuel, and concrete (Ramaswami et al., 2008). As more of these consumption-related emissions are incorporated into a cities inventory, then the inventory increasingly begins to capture more of the cities "carbon footprint."

The academic community has been active in developing hybrid methods that combine production and consumption emissions for cities, and methods for quantifying consumption based emissions typically based on input-output (IO) models. A hybrid life-cycle based trans-boundary GHG emissions footprint was developed by Ramaswami et al. (2008) and evaluated for eight US cities (Hillman and Ramaswami, 2010). Different accounting and reporting approaches for footprints have been developed by Chavez and Ramaswami (2011) including geographic accounting, trans-boundary infrastructure supply-chain (TBIS) footprinting and consumption-based footprinting. Wright et al. (2011) recognize that carbon footprints may impact climate change strategy decision making by cities, Beyond hybrid approaches, IO models have been developed to capture the direct and embodied primary energy requirements of local household expenditures (Larsen and Hertwich,2009; Baynes et al., 2011) For a comprehensive approach, Schulz (2010) suggests including upstream and downstream processes of connected socioeconomic systems and the indirect life-cycle related emissions of imported and exported goods. Upstream emissions increase the overall emissions, whereas downstream emissions are excluded from overall emissions, thereby resulting in trade-corrected estimates of indirect emissions, which still exceed direct emission accounts (Schulz, 2010). Building upon these academic studies, some cities are beginning to incorporate new consumption-based emissions into their GHG inventories. The focus of this paper, however, is primarily on the existing institutional protocols that are used internationally.

There are several international sources where community GHG inventory results for cities have been collected. These include the carbon disclosure project (CDP) report on C40 cities; the “Carbonn” Cities Climate Registry 2011 annual report; and both the UNEP and the World Bank urban websites. It is increasingly recognized that while local governments do most of the inventorying they are not solely responsible for all of the emissions in community inventories. Arup (2011) have shown that there many differences between cities in terms of what GHG emitting sectors they have control over; and in particular that higher levels of governments typically have greater control over energy supply systems. Addressing climate change in cities is a multi-level governance issue (Corfee-Morlot et al., 2009).

3. Comparison of Inventory Frameworks

Findings from seven prominent international GHG emissions inventory frameworks for cities or regions are presented in this paper. These are categorized into community, corporate and upstream GHG emissions.

Four of the frameworks are for community GHG emissions:

1. Global reporting standard in the International Local Government GHG Emissions Analysis Protocol (version 1.0) by the International Council for Local Environmental Initiatives (ICLEI) (ICLEI, 2009), referred to hereon as "ICLEI." (Note that ICLEI is in the process of revising this protocol jointly with C40.)
2. Baseline emissions inventory guidelines developed with the European Commission's Covenant of Mayors (EC-CoM), Part II in How to develop a Sustainable Energy Action Plan (Covenant of Mayors, 2009), referred to hereon as "EC-CoM."
3. International Standard for Reporting Greenhouse Gas Emissions for Cities and Regions by UNEP, UNHABITAT and the World Bank (UNEP, UNHABITAT and World Bank, 2010), referred to hereon as "UN/WB."
4. Greenhouse Gas Regional Inventory Protocol (GRIP) developed by Tyndall Centre for Climate Change Research, University of Manchester and UK Environmental Agency (GRIP, 2008), referred to hereon as "GRIP." This protocol is used by the European Network of Metropolitan Regions and Areas (METREX)

With regards to corporate emissions (corporate emissions are those emitted by municipal operations, e.g. City Hall lighting and waste vehicle operation; the terminology is consistent with WBCSD/WRI corporate reporting - private corporation), ICLEI and EC-CoM have also developed protocols for corporate GHG emissions, in addition to two other frameworks applied to corporate GHG emissions:

5. The GHG Protocol: A Corporate Accounting and Reporting Standard by the World Resources Institute and the World Business Council for Sustainable Development (WRI/WBCSD, 2004), referred to hereon as "WRI/WBCSD."
6. Greenhouse Gases ISO 14064:2006. Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals developed by the International Standardization Organization (ISO, 2006), referred to hereon as "ISO."

Due to its unique nature in incorporating and calculating upstream emissions, the following protocol is also included:

7. Bilan Carbone - Methodological Guide for Companies and Local Authorities developed by the Agènce de l'Environnement et de la Maîtrise de l'Energie (ADEME, 2007), referred to hereon as “Bilan Carbone.”

ICLEI and EC-CoM have protocols for both community and corporate emissions, UN/WB and GRIP are protocols for community emissions only, and WRI/WBCSD and ISO are protocols for corporate emissions only.

The rest of this section outlines the similarities and differences between the four community GHG emissions inventory frameworks for cities and urban regions (Table 1), using the IPCC standard as a reference. Six elements are identified for comparison, and demonstrate similarities and differences among the methodologies that have an impact on GHG inventory values, these are:

- Boundaries and definitions of emissions attribution
- Sectors included
- Treatment of lifecycle emissions
- Calculation methods
- Data precision
- Reporting format

Four protocols – ICLEI, EC-CoM, UN/WB and GRIP – were chosen for comparison as they are frameworks, methods or software that have been applied internationally, i.e., they have been used to determine GHGs for cities or urban regions in more than 10 countries.

3.1 Boundaries and Definitions of Emissions Attribution

All four standards can be used to determine city-wide emissions based on the spatial political boundary of a city. GRIP was technically developed for regional reporting; UN/WB can be used for both cities and metropolitan regions. ICLEI and UN/WB use or recognize the World Resources Institute (WRI) definitions of Scope 1, 2 and 3 emissions; however this terminology is not used by GRIP nor EC-CoM. The scopes are defined as:

Scope 1: Direct emissions produced within the spatial boundary of the urban area.

Scope 2: Indirect emissions produced outside the urban boundary, but as a direct result of activities within the boundary; limited to electricity and district heating/cooling.

Scope 3: Further indirect or embodied emissions produced outside the urban boundary as a result of activities within the boundary.

3.2 Sectors Included

All four standards report Scope 1 and Scope 2 energy emissions. In addition, all four standards report Scope 1 emissions from waste and wastewater treatment processes. EC-CoM does not report Scope 3 emissions from waste and wastewater treatment processes; though the other three standards do. UN/WB report aviation and marine emissions from all trips originating in the city. GRIP reports emissions from all domestic aviation and marine activity. These emissions are optional for ICLEI, and they are not included in EC-CoM. UN/WB, and GRIP require reporting of scope 3 transmission and distribution lines losses; EC-CoM does not, and ICLEI is unclear. ICLEI, UN/WB, and GRIP report industrial process emissions whereas EC-CoM does not. UN/WB and GRIP report emissions from agriculture, forestry, and other land uses (AFOLU), though it is optional for ICLEI, and not included in EC-CoM.

3.3 Treatment of Lifecycle Emissions

ICLEI and UN/WB encourage reporting upstream emissions from materials and fuel consumption as informational items. EC-CoM offers the option to use life cycle emission factors in calculations as an alternative to standard emission factors; this offers the option to capture upstream emissions from fuel consumption. GRIP does not encourage additional upstream reporting beyond Scope 2 and Scope 3 waste, wastewater, electrical T&D losses, and aviation and marine emissions.

3.4 Calculation Methods

All four standards apply emission factor-based methodology (as per IPCC); that is, emissions are typically calculated as follows:

$$GHG\ Emissions = Activity\ Data \times Emission\ Factor$$

Activity Data refers to the level of a certain activity (e.g. electricity consumption) and *Emission Factor* represents the emissions resulting per unit of activity (e.g. tCO_2e/GWh of electricity). Activity data required for calculating energy emissions is consistent across all four standards: stationary combustion is the total quantity of fuel consumed within the boundary, electricity emissions is the total quantity of electricity consumed within the boundary, and mobile combustion (transport) is the total quantity of transport fuels consumed within the boundary.

There are several ways of calculating GHG emissions from waste (Mohareb et al., 2010), and the various standards are generally ambivalent on which approach is preferred. The ideal approach is to use emissions from waste physically released during the inventory year (i.e. “waste-in-place”), calculated using the First Order Decay method (as now required by ICLEI). However, data requirements are intensive, requiring a time series of at least 20 years of waste data. Most inventories completed using the UN/WB standard have reported emissions embodied in the waste produced during the inventory year, calculated with an adaptation of the Total Yield Gas method. Data requirements for the Total Yield Gas method are more widely available.

3.5 Data Precision

ICLEI, UN/WB, and GRIP allow for activity data with varying degrees of precision depending on availability, similar to the IPCC’s “Tier 1, Tier 2, and Tier 3” approach. EC-CoM requires activity data specific to the study city and discourages estimates based on national averages. All four standards allow for emission factors with varying levels of precision, including IPCC default emission factors (IPCC Tier 1) and country-specific emission factors (IPCC Tier 2).

3.6 Reporting Format

EC-CoM, and UN/WB require reporting of activity data and emission factors (EC-CoM provides emission factors), as well as GHG emissions; though ICLEI and GRIP do not. UN/WB and GRIP require reporting of data precision (Tier or Level); though EC-CoM and ICLEI do not. The energy sub-sectors vary between standards. UN/WB and GRIP require sub-sectors corresponding to those required by the IPCC. ICLEI divides all stationary combustion into three sectors (residential, commercial, and industrial) and groups all transport emissions together. EC-CoM requires emissions reported in sectors corresponding to municipally controlled emissions and non-municipally controlled emissions. ICLEI and EC-CoM provide separate reporting of emissions associated with municipal operations (also known as corporate emissions); UN/WB and GRIP do not report corporate emissions.

4. Impacts of Inventory Framework on GHG Emission Results

To further understand how differences in methodologies impact urban GHG inventories, the GHG inventory frameworks have been applied to, New York City, Shanghai, and Paris as shown in Tables 2, 3 and 4. The results are divided into three distinct applications: applying ICLEI, EC-CoM, WRI and ISO frameworks to corporate emissions for New York City; applying ICLEI, EC-CoM, UN/WB and GRIP frameworks to community emissions for Shanghai; and applying GRIP and Bilan Carbone frameworks to emissions for Paris (the latter of these two frameworks includes substantial upstream emissions).

Note that none of the results shown in these tables constitute the official or accepted GHG inventory of any of these cities. The purpose is to demonstrate how the total emissions vary as a result of the inclusion or exclusion of specific inventory components. The tables have been determined by drawing upon a single inventory for each city or region. There could be further variation in the reported emissions for some individual components of the inventories; for example, values reported for waste emissions could differ depending upon the assumptions made in software or calculations undertaken using the frameworks. Moreover, the EC-CoM has a flexible reporting philosophy, permitting emissions values to be determined by a range of different approaches (to accommodate different software used in various European nations). A final caveat is that neither EC-CoM nor GRIP recognizes the concept of scopes used to present the results in Tables 2, 3 and 4, however these were inferred for illustrative purposes.

4.1 Corporate Emissions – New York City

New York City is the most populous city in the U.S., and the center of the New York metropolitan area, which is one of the most populous metropolitan areas in the world. With a population of 8.4 million over a land area of 1,214 square kilometers (City of New York, 2010a), New Yorkers' activities emit less carbon per capita than those of residents of comparable American cities and emit about a third as much as the activities of the average U.S. resident. This is a result of the city's high rate of commuting with public transit and walking, low automobile ownership, and low per capita electricity consumption. The city has limited industrial and agricultural activities (City of New York, 2010b).

Using the municipal GHG emissions data for New York City (City of New York, 2010b), an evaluation of the corporate inventory was carried out using the following four protocols: ICLEI, EC-CoM, WRI/WBCSD and ISO. The New York City corporate GHG emissions are tabulated in the way the New York City inventory publication is reported, and is used as the base case against which the other four protocols are compared. The results demonstrate the extent to which these protocols capture New York City's published inventory, and provide insight into implications of using different protocols and impacts on city-level decision-making regarding GHG emissions and climate change. Emissions values in Table 3 are based on the New York City GHG emissions data for corporate emissions based on the 2009 fiscal year, as published by PLANYC: Inventory of New York City Greenhouse Gas Emissions (City of New York, 2010b).

New York City reported total corporate GHG emissions as 3,950,881 t CO2 e, broken down as Scope 1: 1,620,391 t CO2 e, Scope 2: 1,484,392 t CO2 e; and Scope 3: 845,558 t CO2 e. Table 3 shows that New York City does not report on several components. Scope 1 corporate GHG emissions are comparable among the protocols, whereas 100% of Scope 2 emissions are captured by WRI/WBCSD, and only captured 6% by ICLEI, EC-CoM and ISO due to the exclusion of the bulk of Scope 2 comprising indirect emissions from electricity. The protocols capture between a half and three quarters of Scope 3 emissions, with EC-CoM capturing the least at 51%. The WRI/WBCSD captured the most, at 94% of the total corporate GHG emissions reported by New

York City, the difference being the result of the biogenic CO_2 from fuel which is reported by New York City's inventory but not reported by any of the four protocols.

The underlying equations behind the GHG emissions reported involving activity data and emission factors are subject to variation, not only in the availability of the data, level of complexity of emission factors, or the challenge of gathering data from a large number of sources for every sector, but also in the subjectivity surrounding which buildings and facilities to include, industrial processes and agricultural practices to consider, and how far upstream beyond city boundaries is envisioned. This subjectivity produces uncertainties that are inevitable, however still produce meaningful results if conservative approaches are taken, thereby assuming worse consequences which will produce more stringent emission reduction targets at the city-level. Uncertainty assessment and quality assurance are encouraged and should follow IPCC guidelines (IPCC, 2006). Indirect out-of-boundary emissions (Scope 2 and 3) should be reported such that no double-counting occurs between cities, however, some Scope 3 emissions may involve inevitable double-counting, and should be carefully scrutinized when using city emissions for country totals.

4.2 Community Emissions – Shanghai

Shanghai is the most populous city in China, and is located in eastern China, at the middle portion of the Chinese coast. (Li et al., 2010). Once a fishing and textiles town, it has been growing rapidly in the last two decades, and is commonly described nowadays as the showpiece of the booming economy of China. With a population of 18.2 million over a land area of 6,200 square kilometers, it has been the subject of rapid re-development in the 1990s and is home to the world's busiest container port (Shanghai Municipal Government, 2006). The top three largest service industries are: financial services, retail and real estates, however it does also have a heavy manufacturing industry but a very limited agricultural industry.

Using the energy demand and carbon emissions data for Shanghai an evaluation of the city inventory for community emissions was carried out using the following four protocols: ICLEI, EC CoM, UN/WB and GRIP. .Emissions were primarily due to electricity consumption and heating and industrial energy use, followed by the transportation sector. Like many Chinese cities, Shanghai relies primarily on coal for power production. The share of coal in thermal power generation is exceptionally high (87%), making the GHG intensity of power production higher than other global cities. Shanghai is the largest producer of steel (~19 Mt) in China, and the second-largest worldwide, and accordingly, has the highest industrial emissions per capita from the metal industry. Shanghai's per capita emissions from aviation and marine are one of the highest in China, indicating that it is the most active hub of international economic activity and trade. The bulk of the emissions are produced by the electricity, heating and industrial sectors, largely due to the predominately coal-based energy structure.

Table 2 shows that the UN/WB reports the highest value of emissions (235,501,000 tCO_2e) followed by GRIP (227,369,000 tCO_2e) and ICLEI (220,177,000 tCO_2e), which are comparable in value though ICLEI does not include Scope 3 emissions, and GRIP excludes international aviation and marine fuels. EC-CoM captures the least emissions, also for not reporting Scope 3 emissions, and for including only stationary and mobile combustion and waste/wastewater emissions under Scope 1. To put the differences in quantified emissions in perspective, note that Shanghai is producing more emissions than many countries. When compared to the GHG emissions (excluding forestry and land use changes) reported to the United Nations Framework Convention on Climate Change (UNFCCC) by countries, Shanghai ranks about 30th. This reality makes it important to consider that action to reduce GHG emissions is just as necessary at a city-level as it is at a national level.

4.3 Upstream and Embodied Emissions – Paris

Paris is a highly dense city of 2,125,000 people, within the much larger Ile de France region. The pace of construction is slow, and 70% of the buildings date prior to the first thermal regulation of 1974, and exhibit a significant lack of insulation. Industry in Paris is almost non-existent with a single industry placed in the national plan allocation of CO_2 quotas – that being the Compagnie Parisienne de Chauffage Urbain (Mairie de Paris, 2007). Ile-de-France, where Paris is located has a population of 11.7 million in 2008, making it the most populous region in France (GRIP, 2009).

As Paris has one of the most well developed GHG inventories for upstream emissions we sought to compare its inventory with another based on more conventional practice – to identify differences in methodology and impacts on the quantity of emissions reported. The 2005 GHG emissions for Paris developed using the Bilan Carbone method (Mairie de Paris, 2007) were compared in per capita terms with the 2008 GRIP Inventory (GRIP 2009) for Ile de France (population 11,694,000). The comparison was furthermore conducted by adapting the measures from each of the two methods into the UN/WB reporting framework.

While some differences between the two methods were expected due to the differences in spatial boundaries and treatment of upstream emissions, the results were quite surprising. The per capita emissions for Paris using Bilan Carbone were approximately four times higher than those for Ile de France using GRIP (Table 4). For some sectors the two methods produced similar results; stationary combustion emissions were 3.03 tCO2e per capita by Bilan Carbone, and 2.53 tCO2e per capita by GRIP; emissions from waste were also similar. Most of the difference occurred with emissions for mobile combustion, which were 14.76 tCO2e per capita with Bilan Carbone compared to just 1.49 tCO2e per capita with GRIP. Much of this is due to extremely high aviation emissions captured determined by Bilan Carbone, while GRIP only includes domestic aviation emissions. The Bilan Carbone methodology for air travel considers both travel to and from Paris airports. Bilan Carbone also report just over 5 tCO2e per capita for road transportation emissions from light duty vehicle and trucks. Much of this is probably upstream emissions, occurring outside of the City of Paris; given its high density and substantial public transportation, we would expect Paris' road transportation emissions to be closer to 1 tCO2e per capita. Other upstream emissions clearly included by Bilan Carbone, but not in GRIP were those for food (1.42 tCO2e per capita) and materials (0.73 tCO2e per capita).

Applying the data for Paris by GRIP to the UN/WB standard was a fairly straight forward process because of the similarities in the inventory components. If scaled to the population of Paris in 2007, the total community GHG emissions for Paris by GRIP was calculated to be 10,838,520 tCO_2e, of which 100% has been captured by the main UN/WB reporting tables. Conversely, the application of Paris data by Bilan Carbone to the UN/WB standard was a challenging exercise due to the distinctly different inventory components. The total community emissions for Paris by Bilan Carbone was calculated to be 40,145,000 tCO_2e, of which 38,187,000 tCO_2e was captured by the main tables of the UN/WB standard, thus representing 95% of the total reported emissions, equivalent to 17.970 tCO_2e per capita. The difference of 2,083,000 tCO_2e, accounts for the embodied energy in food consumption and packaging of products containing glass, cardboard, paper, plastic and metals. This is not accounted for in the main UN/WB standard, but would be reported in Table 4 of the UN/WB standard.

GRIP has been applied to 18 European regions ranging from as far north as Helsinki to as far south as Athens (GRIP, 2009), and is quite adaptable to the UN/WB protocol. Bilan Carbone was mainly designed and geared towards the needs of French cities. However, some of the French cities are located in overseas territories and thus in different climatic zones than the cities of mainland France. Specific emission factors have therefore been calculated for these territories (ADEME, 2007), though interesting, it points to the success of the UN/WB standard in incorporating inventory components from Bilan Carbone despite being geared towards French cities, thus providing good evidence of the comprehensiveness and adaptability of the UN/WB standard to global cities. The UN/WB standard has been successful in incorporating the majority of the Bilan Carbone inventory components because of the inclusion of a large proportion of Scope 3 emissions which captures the focus of the Bilan Carbone – namely upstream and embodied energy of buildings, transportation, and consumption of goods and services including food.

The Bilan Carbone methodology makes a clear separation between the resulting emissions from Parisians versus visitors in terms of transportation (by car, bus and air) and food consumption, which represents around 45 million visitors versus 2.125 million residents (Mairie de Paris, 2010). The implications for climate policies resulting from this separation could be interesting. Regardless of the protocol used, the energy sector comprising stationary combustion, mobile combustion and emissions from fugitive sources comprise the majority of the reported community emissions, ranging from 79-99%.

5. Discussion

Collection and publication of public information is traditionally the purview of national governments, enabled by sophisticated and experienced statistics agencies and supported by relevant ministries and departments. Under the UNFCCC, for example, most countries are reporting national GHG inventories that facilitate relatively straightforward comparisons across countries and over time. Cities, however, are emerging as the centre of much of the 21st Century’s economic, social, and environmental discourse, and they generate the majority of the world’s GHG emissions (Hoornweg et al. 2010, 2011). Reporting of these emissions has largely been conducted by cities themselves, often supported by or delegated to the academic community. Cities are already showing significant leadership in mitigating emissions. To further support this innovation, promote policy dialogue, and target financing, inventory methodologies specific to the capabilities and requirements of local governments are needed. These inventories must be compatible with national and international practices, as well as being locally pragmatic, globally consistent, and verifiable. Furthermore, GHG emissions are but one of many indicators that cities and the agencies that support them are tasked with regularly reporting. The value of monitoring and clearly integrating indicators into overall service provision is highlighted in cities like Amman, New York City, Tokyo, Toronto, Mexico City, Bogota, and Sao Paulo. Their experiences show that consistent measurement is a prerequisite for sustained improvement.

For, New York City, Shanghai and Paris, studied here, a knowledge of the cities' population, land area, economy, energy mix, industries, transportation modes, significant environmental regulations and climate policies (if any) greatly enhances the understanding of their respective inventories. Though the GHG emissions inventorying process is applied to three cities in this paper, the findings of this research evaluate the GHG emissions inventory protocols with respect to their comprehensiveness of city-level activities, appropriateness of their application to cities in developed and developing countries, and in countries with economies in transition. The results provide a measure of how well the inventory results are representative of climate change challenges faced by cities. In the absence of an agreed-upon international GHG emissions inventory protocol or standard, the findings of this research provide recommendations on best practices in the utilization and application of GHG emissions inventory protocols for cities.

Activity data varies with each of the inventory components; for example, it may refer to the consumption of energy or production of waste. In calculations for cities, activity data is specific to the city while emission factors are often based on the basic method, frequently utilizing IPCC-recommended country-level defaults, referred to as Tier 1 data source. This paper does not get into the specifics of the GHG emissions calculations, but rather uses totals in units of tons of CO_2 equivalent (tCO_2e factored to include the global warming potentials for other GHGs when considered relevant in the respective protocols). The results touch upon the issues of double-counting which is particularly relevant in indirect emissions occurring out of city boundaries as a result of activities within the city (Scopes 2 and 3) and the uncertainties involved in the inventory components.

With regards to GHG emissions for communities, all protocols consistently include Scope 1 emissions pertaining to energy from residential, commercial, institutional and industrial buildings; transportation; and direct emissions from waste and wastewater; in addition to Scope 2 emissions. Though the four community protocols include Scope 1 emissions which are similar to the IPCC emissions inventory components at the country-level, the Scope 1 emissions are always part of the inventory because they include direct emissions that occur within the territorial boundary of the city. However, some of the discrepancies in Scope 1 emission components lie in the AFOLU, industrial processes and fugitive emissions. Neither ICLEI nor EC-CoM include AFOLU. Industrial and fugitive emissions are included in all but EC-CoM. The differences are greatest amongst the protocols when considering Scope 3 emissions. EC-CoM does not include Scope 3 emissions in its entirety, whereas the UN/WB standard includes all components of Scope 3 considered here. ICLEI only includes indirect emissions related to waste and wastewater. GRIP includes some components of Scope 3, however excludes international aviation and marine travel.

As for corporate GHG emissions which are usually a subset of community GHG emissions, only Scope 1 emissions pertaining to direct emissions from buildings and facilities, and energy use in water and wastewater treatment and distribution; and Scope 2 emissions pertaining to municipal public lighting and traffic lights are consistently included in all protocols. Waste and other direct emissions are included in all but EC-CoM. WRI/WBCSD goes beyond the other protocols in the coverage of Scope 1 emissions to include physical and chemical processing and fugitive emissions. Only WRI/WBCSD goes beyond what is included in Scope 2 emissions by the other protocols, and includes indirect emissions from electricity and indirect emissions from transmission and distribution. Similar to the GHG emissions for communities, the majority of discrepancies lie in what is included in or excluded from Scope 3 emissions, however the protocols all agree in including the energy pertaining to the municipal fleet. Employee commute is considered in all but EC-CoM. WRI/WBCSD includes the most coverage of Scope 3 components – this includes components such as the upstream energy in the extraction and production of materials and fuels, transport and electricity related emissions not covered in Scope 2, embodied energy in the use of products and services and waste disposal.

Cities using any of the seven GHG emission frameworks discussed in this paper are already providing an important contribution to public disclosure and GHG mitigation. Services such as Carbonn and the Carbon Disclosure Project (CDP), which allows multiple frameworks for inventory submissions, provide a convenient platform for compilation of city-level GHG emission reporting. ICLEI's methodology provides a greater degree of information in one area by further disaggregating corporate (municipal) emissions. The UN/WB methodology has been used by the academic community to complete inventories on behalf of cities, e.g. Bangkok, Beijing, and Shanghai.

Ideally, linkages across data compilation websites will streamline GHG reporting, and data entered in one location could be immediately available across facilities. Redundancy of information is important. The UN/WB table of cities with peer reviewed GHG emissions baselines (a likely prerequisite for international financing and emissions trading systems) will be regularly updated and available on UNEP, UN-HABITAT, and World Bank websites. It will also likely link to other organizations, including Carbonn, CDP, IPCC, and the Global City Indicators Facility. The open-source nature of information, adherence to globally accepted standards (such as a potential standard with the International Organization for Standardization), and regularly updated reporting are critical to GHG inventories for cities. Inventory experience and research will enable refinement of Scope 3 emissions.

To facilitate benchmarking and policy development, a common approach is needed that meets the needs of cities, urban researchers, climate financing, and national monitoring and reporting requirements. The frameworks reviewed in this paper are sufficiently similar to merge into a common framework. Data for existing inventories reported to the UN/WB is either derived from existing agency databases, national statistics, and academic research or provided by city-staff. Cities reporting to Carbonn and CDP will likely have exclusive provision of data by municipal staff (e.g. corporate emissions data plus city and possibly region-wide).

Tables 2, 3 and 4 suggest how a common approach could emerge. Under Scopes 1, 2 and 3, the categories are common in all – although some inventories do not report some categories. AFOLU, for example, is a relatively minor contribution, although in some inventories such as GRIP, which is more of a regional approach (as opposed to a more confined city boundary), land use changes may have a greater impact. A case could be made that initially inventories could exclude AFOLU and possibly aviation and marine emission, or at a minimum reported separately. Similarly, as cities undertake more research, Scope 3 emissions will be better defined and the list will grow, e.g. inclusion of embodied emissions in building materials and food, as is the case in the Bilan Carbone. If all inventories clearly denote what is included and excluded comparability is possible. Establishing a comprehensive, transparent, and linked data collection system with consistent definitions, credible governance structures and availability of capacity building support are essential first steps in that direction.

6. Recommendations

On the encouragement of reviewers of this paper, we provide the following recommendations for city officials wishing to act upon the findings of this comparison of frameworks. These recommendations are given by drawing upon the strongest aspects of the protocols studied, but without prejudice against any one of them:

i) City inventories should clearly distinguish between direct, in-boundary emissions and upstream emissions. One way of doing this is by use of the WRI Scope 1,2,3 terminology. Although not all of the frameworks currently use this terminology, it would probably not be too difficult for them to do so. Clearer rational for the difference between scope 2 and scope 3 emissions in community inventories may, however, be warranted.

ii) Regardless of which framework cities are currently using, it would be advisable for them to start reporting more complete direct and further upstream emissions, at least as information items. There is growing recognition that cities give rise to substantial upstream emissions beyond their boundaries, and efforts to quantify and standardize these emissions are increasing.

iii) Cities should always report activity data (such as energy consumption) and emissions factors with their emissions inventories. As well as helping to verify and provide confidence in inventories, the underlying data also provides critical understanding that is required to plan emissions reductions. GHG inventories without activity data and emissions factors are missing information on the key drivers.

iv) Emissions inventories often include data with varying degrees of confidence, so cities would be advised to develop means for expressing data quality. This could be a simple, pragmatic colour coded system such as developed by GRIP, or use of the IPCC's tier system. Regular reporting of values, ideally annually, also facilitates continuous improvement of data quality.

v) State who conducted the inventory (e.g. city staff, consultants, academic researchers), and indicate the emissions sources included (e.g. aviation and marine emissions);

vi) Clearly define the spatial boundary (as differences in per capita transportation, AFOLU, industrial process and other emissions might be expected between inventories of central cities versus metropolitan regions);

vii) Take precautions to avoid "double counting", and use terminologies and emissions factors consistent with IPCC national inventories;

viii) Facilitate local or metropolitan reporting (aggregated local governments) to maximize potential mitigation opportunities and potential funding.

ix) Ensure consistency with state/provincial and national inventories to facilitate aggregation of cities values.

7. Conclusion

To help in reducing GHG emissions, various inventory protocols that cater to the needs of the city have been developed. These typically include components which are city-specific, and yet some may exclude components that could potentially be significant in nature and magnitude. A number of GHG emissions inventories are currently in practice, though to facilitate dissemination and mutual learning among cities, a single GHG emissions inventory protocol applicable to all cities worldwide needs to be globally agreed upon. Inventory results need to be relevant, complete, consistent, transparent and accurate (ICLEI, 2009).

In the absence of a global agreed-upon GHG emissions inventory protocol, GHG emissions inventories better reflect complete CO_2 emissions when accounting for as many components as possible, i.e., by including as many of the out-of-boundary and upstream emissions as is reasonably feasible. Upstream emissions and embodied energy in products and services amount to 25% or more of the total reported inventory, and need to be included to effect strategic climate change policies that reduce city emissions without unknowingly creating adverse effects in other parts of the world bearing responsibility for such emissions. However, when such an exercise becomes an overwhelming activity for a city, then an appropriate choice of inventory becomes critical in reflecting actual city conditions and economy. For example, a city with limited industrial activity such as New York or Paris, need not consider an inventory that is industry-specific or industry emissions-intensive.

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Table 1: Similarities and differences between four leading reporting frameworks (IPCC requirements provided for comparison purposes)

	ICLEI	EC-CoM	UN/WB	GRIP	IPCC
Boundaries and Definitions of Emissions Attribution					
Requires emissions bounded by geopolitical boundary	√	√	√	√	√
Recognizes WRI definitions of Scope 1, 2, & 3 emissions	√		√		
Sectors Reported					
ENERGY (Scope 1 & 2: electricity, fossil fuel combustion, district heating/cooling)	√	√	√	√	√
Electricity transmission and distribution (T&D) losses (Scope 3)	unclear		√	√	√
Aviation and marine emissions (Scope 3)	optional		all	domestic	domestic
INDUSTRIAL PROCESSES (Scope 1)	√		√	√	√
WASTE AND WASTEWATER (Scope 1)	√	√	√	√	√
WASTE AND WASTEWATER (Scope 3)	√		√	√	√
AFOLU (Scope 1)	optional		√	√	√
Treatment of Lifecycle Emissions					
Encourages reporting upstream emissions from materials and fuel consumption	√		√		
Accepts a Lifecycle Assessment inventory as an alternative to a standard inventory		√			
Calculation Methods					
Requires an emission factor-based methodology	√	√	√	√	√
Data Precision					
Allows estimates based on national statistics in the absence of precise activity data	√		√	√	N/A
Allows use of IPCC default emission factors	√	√	√	√	√
Reporting Format					
Requires reporting of activity data and emission factors used in calculations		√	√		√
Requires reporting of data precision tier or level			√	√	√
Requires energy emissions reported according to IPCC energy sub-sectors			√	√	√
Requires energy emissions reported according to alternate sub-sectors	√	√			
Requires additional reporting of government operations (corporate emissions)	√	√			

Table 2: 2009 GHG emissions inventory for New York City presented with four inventory frameworks, tCO_2e.

(Note: Based on 2009 GHG emissions inventory data from Dickinson, J. and R. Desai. 2010. “Inventory of New York City Greenhouse Gas Emissions, September 2010.” http://www.nyc.gov/html/planyc2030/downloads/pdf/greenhousegas_2010.pdf)

	ICLEI	**EC-CoM**	**WRI/WBCSD**	**ISO**
Scope 1				
Buildings & Facilities	1,062,301	1,062,301	1,062,301	1,062,301
Physical or chemical processing			-	
Energy use in water & wastewater treatment and distribution	444,728	444,728	444,728	444,728
Fugitive			11,354	
Waste	102,548		102,548	102,548
Other	11,354		-	-
SCOPE 2				
Municipal public lighting & traffic lights	83,147	83,147	83,147	83,147
Electricity			1,401,245	
Indirect emissions T & D			-	
SCOPE 3				
Extraction and production of materials and fuels			-	
Municipal Fleet	424,259	424,259	424,259	424,259
Employee Commute	15,239		15,239	15,239
Transport-related not in scope 2			-	
Electricity-related not in scope 2			-	
Use of products and services			-	
Waste disposal			177,192	
TOTAL	**2,143,576**	**2,014,435**	**3,722,013**	**2,132,222**
Per capita emissions	*0.254*	*0.238*	*0.440*	*0.252*

Table 3: 2006 GHG emissions inventory for Shanghai presented with four inventory frameworks, tCO_2e.

(Note: analysis based on Shanghai inventory from Sugar, L., C.A. Kennedy, E. Leman. 2011; Scope 3 T&D losses of 6.5% are removed from Scope 2 electricity values; Scope 1 Electricity is under Stationary emissions; Domestic and international aviation emissions estimated from total fuel use, assuming 40% domestic aviation, and 60% international aviation.)

	ICLEI	EC-CoM	UN/WB	GRIP
Scope 1				
Stationary Combustion	145,296,000	145,296,000	145,296,000	145,296,000
Mobile Combustion	20,225,000	20,225,000	20,225,000	20,225,000
Waste / Wastewater	3,086,000	3,086,000	3,086,000	3,086,000
Industrial Processes	22,683,000		22,683,000	22,683,000
AFOLU			*Not Determined*	*Not Determined*
Fugitive/Other	*Not Determined*		*Not Determined*	*Not Determined*
Scope 2				
Electricity	25,899,000	25,899,000	25,899,000	25,899,000
District Heating / Cooling	*Captured as Scope 1, takes place in-boundary*			
Scope 3				
Electricity T&D Losses			1,771,000	1,771,000
Waste / Wastewater	*Captured as Scope 1, takes place in-boundary*			
Aviation (domestic)			3,421,000	3,421,000
Aviation (international)			5,132,000	
Marine fuels (domestic)			2,000,000	2,000,000
Marine fuels (international)			3,000,000	
TOTAL	**217,189,000**	**194,506,000**	**232,513,000**	**224,381,000**
Per capita emissions	*12.0*	*10.7*	*12.8*	*12.4*

Table 4: GHG emissions inventories for Paris (2005) and Ile de France (2008) using two different inventory frameworks (tCO_2e per capita.)

UN/WB Components	SCOPE	GRIP, 2008	Bilan Carbone, 2005
Energy		**4.020**	**17.798**
Stationary Combustion		**2.531**	**3.043**
Electricity (incl. T&D losses)	1,2,3	-	2.936
District heating or cooling, CHP, and energy from waste	1,2,3	-	-
Commercial & Institutional	1	0.834	-
Residential	1	1.366	-
Manufacturing Industries & Construction	1	0.331	0.107
Mobile Combustion		**1.485**	**14.755**
Road transportation: LDVs	1	-	3.316
Road transportation: trucks	1	-	2.737
Road transportation: other	1	-	0.060
Railways	1	-	0.004
Domestic aviation	3	-	8.637
International aviation	3		
Domestic marine	3	-	0.001
International marine	3		
Fugitive Sources		**0.004**	**-**
Industrial Processes	1	**0.302**	-
AFOLU	1	**0.591**	-
Waste		**0.188**	**0.173**
Solid waste disposal on land	1,3	0.188	0.173
Waste incineration	1,3	-	
Wastewater handling	1,3	-	-
SUB TOTAL per capita emissions		**5.100**	**17.970**
Food	3	-	1.416
Glass, cardboard, paper, plastic, metals	3	-	0.725
TOTAL		**5.100**	**20.111**