SUSTAINABLE CITIES

Assessing the Performance and Practice of Urban Environments

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ASSESSING URBAN GREENHOUSE GAS EMISSIONS IN EUROPEAN MEDIUM AND LARGE CITIES: METHODOLOGICAL CONSIDERATIONS

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The world's cities are responsible for a large and growing share of the anthropogenic greenhouse gas emissions widely believed to underlie observed climate change. We need to locate and quantify those emissions if we are to mitigate them; however, the development of consistent and reliable emissions inventories has proved challenging. This chapter examines selected methods to determine greenhouse gas emissions at the urban scale. We describe the various criteria considered when constructing an urban greenhouse gas protocol including the definition of urban, the gases that are measured, the source they come from, the scope of analysis and how the measurements are undertaken. We then present results for European medium and large-sized cities derived from alternative methodologies to demonstrate the range of results. Finally, we briefly discuss the policy implications of the various approaches.

Introduction

Policy-makers need clear, consistent, and reliable information about the location of greenhouse gases (GHG) and drivers of emitting activity in order to design appropriate mitigating strategies. Until recently, the most consistent and reliable information on GHG emissions has been for countries, following data collection protocols designed for the Intergovernmental Panel on Climate Change (IPCC). Focus has more recently shifted towards developing GHG emissions estimates at sub-national levels, especially for cities, where the majority of the global population and economic activity is now concentrated.[1] Existing research suggests that cities in aggregate are responsible for somewhere between 40 per cent and 80 per cent of global GHG emissions.[2] Considerable debate remains over appropriate methodologies for preparing city-level estimates of anthropogenic GHG emissions. Such debate has evolved because GHGs are typically not directly measured but estimated by extrapolating from activities that produce GHGs, such as fossil-fuel combustion.

The goal of this chapter is to overview some of the methods used to create urban GHG inventories and discuss the benefits and pitfalls of each using European medium and large-sized cities. In the next section, we overview selected criteria for creating an inventory. This is followed by a presentation of urban GHG emissions results for European cities from different types of analyses. We conclude with a discussion of the implications for the use of different methods.

Criteria to consider

As early as the 1980s, municipalities were preparing action plans for GHG emissions reductions based upon inventories.[3] Over time the methods for estimating urban GHGs have increased in complexity and depth. As will be discussed below, the debate over appropriate methodologies for generating comparable urban-emission inventories has yet to be resolved.[45] Generally concerns come under three categories: what geography should be included; what should be measured; and, how should it be measured.[6]

What is urban?

Defining the exact spatial and functional urban boundaries for measurement is of particular importance in generating accounts that represent conceptually comparable spheres of economic and social activity. Researchers use a number of different criteria to define urban areas and these differences have important implications.[7] GHG measurements are sometimes restricted to the political borders of a municipality to reflect the legitimate scope of government and help in the development of climate change action plans,[8] such as for Toronto,[9] Vancouver,[10] New York City,[11] and Sydney.[12] Some researchers argue for even finer-scale inventories. For example, analysts have suggested that the county level in the USA is the best definition for urban, as it matches policy-maker needs and is the smallest unit for which energy data are readily available.[13]

The urban sphere of influence extends well beyond the city's primary jurisdiction and immediate suburbs into outer suburbs and peri-urban lands. 'Upstream', urban residents depend on the production of emission-intensive consumption items (i.e. agricultural goods, construction materials like steel and concrete). 'Downstream', they require the steady disposal of waste products (e.g. in landfills and effluent from wastewater treatment plants). Urban areas are also hubs of regional and international transport, from which emissions are generated well beyond any urban-related boundary. Some urban GHG studies therefore include local jurisdictions surrounding a central city, such as its immediate suburbs. For example, while the City of Chicago performed a municipal inventory of GHG emissions, they also estimated one for the metropolitan region.[14] While GHG emissions estimates from wider urban agglomeration boundaries are rare, some are being developed through spatial global and regional fossil fuel emissions estimates.[15] Other studies have estimated partial carbon footprints, including those of the 100 largest metropolitan areas in the USA in 2000 and 2005.[16] Finally, some researchers apply methods which systematically account for cross-boundary contributions of GHG emissions through consumption of key materials.[17] This issue of scope definition, to which we return below, further extends the boundaries of urban areas to those 'distant elsewheres' covered by ecological footprint analysis,[18] and the newer concept of urban land teleconnections.[19]

Amongst the cities that have been studied there is an emphasis on the large urban centres, including New York City, Tokyo, London, Paris, Delhi, and Sao Paulo. This may be due to data availability, the political visibility of these larger cities and their importance in terms of share of urban GHG emissions.[20] Certainly, the field needs additional study of small- to mid-sized cities with a representative range of economic structure as most of the world's urban population lives in smaller urban centres,[21] and these centres might still be less constrained in expanding their existing infrastructure than very large settlements.

Awareness about the implications of boundaries chosen for urban GHG emission inventories is critical for comparative studies and policy analysis. The sectoral and per capita GHG emissions of metropolitan regions arguably are different from those of core municipalities or even smaller units. Comparative studies would ideally encompass consistently defined urban realms. For international studies, this is challenging, as countries define urban areas differently[22] and obtaining comparable data may be difficult.

What is measured?

Methodologies for urban GHG inventories need to be explicit about, at least, three interdependent questions: (1) Which GHGs are included? (2) What resolution of activities by sectors is considered? and (3) What is the 'scope' of the analysis? We examine each of these related issues separately.

First, researchers have a number of greenhouse gases to include in analyses. The most important anthropogenic GHG emissions include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). For inventory development, however, most studies focus on CO_2 and CH_4 emissions. One reviewer suggests that GHGs other than CO_2 are still unknown for urban areas.[23] There are two reasons for this outcome. First, CO_2 accounts globally for approximately 77 per cent of all anthropogenic GHG emissions and is therefore the most important GHG to consider.[24] Second, non-CO_2 GHGs research findings are typically extrapolated from activity data, such as consumption of GHG precursors (e.g. fertiliser use) or output from industrial processes or waste generated. Such data or specific conversion factors are often not available at the urban level. This focus on CO_2 may be increasingly problematic as high impact GHGs could gain in their share of total GHGs in the coming years.[25][26]

The second aspect of 'what is measured' focuses on the detail of GHG-emitting activity sectors or end-uses included in the study. Important end-use sectors include waste and wastewater, energy supply, transport, commercial and residential buildings, industry, agriculture and forestry.[27][28] Kennedy et al. (2009),[29] following the IPCC, suggest that methodologies for urban GHG emissions should include energy conversion and utilisation (e.g. power production, vehicles, oil and gas production and 'fugitive emissions' including emission leakage from natural gas and coal mining and gas flaring), waste, industrial processes and product use, and Agriculture, Forestry and other Land Uses (AFOLU). Not all studies include these sources and GHG emission inventories vary greatly in this regard.

The third aspect of what to measure includes considerations for the allocation of emissions responsibility that exceed spatial system definitions, but occur at other locations. Local inventories often only include emissions from the activities of businesses and residents located within the study area, known as 'direct' emissions. Alternatively, measurements may also include emissions from activities located outside the local jurisdiction but induced through economic activities that are conducted within the jurisdiction, known as 'indirect' or 'deemed' emissions.[30] For instance, power production and waste disposal may be conducted outside cities but relate to the energy and waste disposal needs of urban residents and businesses. 'Traditional' narrowly defined emissions inventories count only emissions that are produced within the study area, regardless of where the related good or service is ultimately consumed, thus placing the responsibility for emissions reduction with the production location.[31]

The World Resources Institute together with the World Business Council for Sustainable Development (WRI/WBCSD) prepared a reporting protocol for corporations,[32] which is increasingly used by researchers examining urban GHG emissions.[33] The protocol addresses this issue by distinguishing among three 'scopes' of emissions. Scope 1 emissions are those from sources under the direct control of the organisation, such as factories or vehicles. They are typically emissions produced in the geographical boundary of the city. Scope 2 emissions are from energy carriers (e.g. electricity, steam, heat, petroleum products) consumed by the organisation, although emissions for their generation/energy conversion are produced elsewhere. If applied to urban areas, Scope 2 emissions include releases outside the geographical boundary of the city that enable energy carrier production for the city.

Scope 3 emissions, also called embodied emissions (up- and downstream), are associated with the extraction, production and transportation of products or services used by the residents of a city. These embodied emissions include those from food production, building material, waste treatment, and also from international aviation and marine transport, as far as it is necessary to sustain urban populations and economic activity. The concept of Scope 3 emission responsibility addresses the notion that all economic activity ultimately is driven by demand for products from consumers. Consequently some researchers argue that consumers should accept the responsibility for all emissions occurring along the entire value chain. In this case, inventories are called consumption-based and allow for the generation of product and service prices to reflect emission related externalities. For equity reasons, it is important to allocate emissions where items are consumed and life-cycle, and consumption-based inventories, which consider cross-scale interactions through trade, are used to calculate these urban emissions 'footprints'.[34] Among the advantages of consumption-based inventories at the national level are that they account for externalisation of emissions through trade, cover emissions from international sea and air transport, increase mitigation options, and encourage cleaner production globally.[35] However, consumption-based inventories also suffer key disadvantages. First, they require more data, particularly about trade, complex calculations, and assumptions that increase data uncertainty. Second, consumption-based methods increase the risk of double-counting and incomparability of inventories across cities. Third, the methods shift the burden of mitigation from production to consumption, neither of which is optimal. For example, if the GHG emissions from a thermal power plant supplying energy to a city and located outside the city boundaries are allocated to the urban area, then the burden for reduction is placed upon the consumers. This approach alleviates responsibility for mitigation by the producer.[36] Given current practices and these weaknesses, scholars and practitioners are now calling for a shared responsibility between consumers and producers.[37]

How is it measured?

There are a variety of ways in which GHG emissions inventories can be compiled and these also vary by gas.[38] The most accurate measurements are sensed or measured directly, but the most common are estimates based upon activity-based extrapolations using emission factors. Two general approaches have been developed to estimate urban GHG emissions. The 'bottom-up' approach begins with defining the study area boundary and relevant activities. Often, bottom-up studies are conducted by local governments using 'in-house' officials, or services provided by consultancies or other outside bodies. A primary benefit of bottom-up measurement is its attention to local context, specific activity levels, and data availability. The bottom-up approach is often relatively comprehensive in scope and accurate in measurement. Various tools have been developed to assist cities in conducting such measurements (Box 5.1), but the use of measurement tools

Box 5.1 Tools for preparing local GHG emissions inventories.[39]

Over the last few years a number of different protocols for estimating local GHG emissions have been developed for use by municipalities, researchers and individuals. Nikolas Bader and Raimund Bleischwitz (2009) reviewed six tools that have been used in Europe including: Project 2 Degrees (developed by ICLEI, Microsoft, and the Clinton Climate Foundation – in English, used by some C40 cities, see www.c40.org); GRIP (developed by University of Manchester, UK -in English, used by several European regions); CO_2 Grobbilanz (developed by Austria's energy agency – in German only); Eco2Regio (developed by Ecospeed – in German, French, and Italian, used by several Climate Alliance cities); Bilan Carbone (developed by French energy agency – in French); and the CO_2 Calculator (developed by the Danish National Environmental Research Institute – in Dutch). One of the major findings of this study was that the six tools vary substantially according to the GHGs included (CO_2 vs other GHGs), the global warming potential (GWP) values used to calculate CO_2 equivalents of other GHGs, the scope of measurement (direct vs indirect), the definitions of sectors, how emissions were quantified (top-down vs bottom-up), how closely the tool follows the IPCC guidelines, and usability of the tool (e.g. simplicity of use, available languages). Given these differences, Bader and Bleischwitz conclude that the tools, developed in isolation from each other, make their resulting measurements 'hardly comparable' across cities or regions. The authors recommend the development of a common tool for conducting local inventories that include all six of the major GHGs covered by the IPCC guidelines, use the most recent GWP values, a complete or at least consistent set of emissions sources, consistent sectoral definitions, and both direct and indirect emissions following a consistent protocol (reporting embedded or life-cycle emissions separately). The authors of this chapter add that the common tool also needs to include a conceptually-consistent definition of the 'urban' or 'region' geography for measurement, as described below.

allows considerable discretion regarding geographic boundaries, scope of included activities, and data sources.[40]

An alternative measurement approach is to construct local emissions profiles from national, regional or global-level emissions measurements, using a consistent methodology for downscaling. This top-down approach can range from simple to more complex, 'hybrid' methodologies. For instance, a simple top-down analysis could estimate local emissions using only the number of people living or working in the local area and the average annual GHG emissions per person across all source categories, according to national statistics. While easy to calculate, these simple estimations can be misleading, particularly since they do not reflect urban-scale variation in economic structure and activity patterns. In addition, simple approaches do not provide much insight when comparing across cities, as any apparent variation reflects only the population size of the cities rather than any meaningful differences in the actual location or source activities of emissions.

Other top-down approaches tailor their inventories somewhat to local circumstances and data availability, even if relying heavily on national, regional or global statistics. For instance, local emissions from electricity production could be estimated by multiplying the amount of electricity produced locally in megawatt-hours (using production data from the power plant) by the regional or national average GHG emissions released per unit of electricity. Similar estimates could be made for other activities, where outcome estimates and relevant 'multipliers' are available.

A more complex top-down method has been developed by Marcotullio et al. (2010).[41] For GHG emissions, they used the Emissions Database for Global Atmospheric Research (EDGAR), version 4.[42] EDGAR includes GHG emissions from fourteen source categories in global grids at 0.1° spatial resolution. For identifying urban geographies and their populations, they used the Global Rural Urban Mapping Project (GRUMP) data.[43] Emissions estimates for European cities are presented in the next section, using this approach.

Top-down approaches have several advantages over bottom-up approaches, including universally comparable definitions of urban areas, the potential to include all major GHG compounds in the analysis for urban centres (including some aviation and navigation emissions), avoidance of double-counting issues, a large number of standardised sources to examine the influences of emissions, and a uniform and replicable methodology to map and analyse emissions. Indeed, top-down methods may be applied at various temporal and spatial scales depending on the location and frequency of measurements, providing useful information about processes and patterns of emissions.[44]

Table 5.1 Summary of coverage in urban GHG inventories.

Variable	Continuum		
What is urban?			
Urban boundary	Political boundary	⟷	All urban GHG-emitting activities
What is measured?			
GHG measured	Only CO_2	⟷	All 6 GHGs in Kyoto Protocol
GWP values	Values from 2^{nd} IPCC report	⟷	Values from 4th IPCC report
Scope	Only direct emissions	⟷	Direct, indirect and life-cycle emissions
Sectors	Limited sectors, different definitions	⟷	All sectors with IPCC definitions
How is it measured?			
Method	Top down (default emission factors)	⟷	Bottom up (regional/ local emission factors)

Source: after Bader and Bleischwitz 2009.[45]

Summary

Urban emissions measurements vary considerably in their operational details. Several issues can be conceptualised as a set of continuums within which researchers choose to build their inventories (Table 5.1). While complex, these topics are a sub-set of a comprehensive range of source activities and estimating techniques. As Kates et al. suggest, 'there is no end to the minutiae of detailed information that is necessary to fully characterize greenhouse gas emissions and emission reduction opportunities'.[46] In principle, comprehensive measurements would include all major GHGs (including carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and other hydrocarbons) and at least all of the major source activities required to be included in national-level emissions inventories according to the IPCC's protocol. Obtaining such comprehensive emissions data for cities is difficult under the best of circumstances. Most often, urban inventories are limited by available data at the appropriate scale, requiring either a limitation in scope or sector that excludes some relevant activities, or top-down methods to estimate local emissions.

Assessment of GHG emissions from European cities

Estimates of GHG emissions for individual cities vary considerably within the literature. For example, estimates of annual GHG emissions per person in London range from 1.2 metric tons[47] to 6.2 tons[48] to 9.6 tons.[49]

Given the variety of techniques used in urban GHG inventories, we compare results from three estimation efforts that aimed to produce comparable figures across cities. The first two efforts follow a bottom-up approach. The first examined GHG emissions in 44 cities around the world, including 20 cities from across Europe, using data from around 2005. The estimation methodology was standardised across each of these cities and reflects a consumption-based approach.[50] The second effort, conducted for the European Commission, examined a large number of cities in eastern, northern, and southern Europe with data mostly from 1998–2001. The protocol was not as rigorously standardised as the first effort, but it has been used as the basis for climate change mitigation and adaptation strategy development in Europe.[51] The third effort reflects our own 'top-down' research, described briefly above. We used spatially disaggregated global datasets to estimate GHG emissions from urban centres worldwide, using data for 2000. This approach contains Scope 1 and 2 GHG-related activities, as well as some airline and navigation emissions associated with urban activities. More details of the methods are presented in other publications.[52]

Bottom-up GHG emissions estimates vary widely across the sample of 42 European cities covered by at least two of the reports (Table 5.2). Estimates in the European Commission (2003) study ranged from 2.5 metric tons per person in Oslo to 11.9 metric tons per person in Pori (Finland), for an average of 6.9 metric tons per person across 25 cities. Kennedy et al. (2009) found slightly higher estimates, ranging from a low of 3.5 metric tons per person in Oslo to 16.0 tons per person in Stuttgart (Germany), for an average of 8.25 metric tons per person across 20 cities. Our estimates ranged from a low of 0.7 metric tons in Blagoevgrad (Bulgaria) to 16.8 metric tons per person in Pori (Finland), for an average of 6.4 metric tons per person across 42 cities.[53] The higher average values from Kennedy et al. (2009) likely result from their consumption-based approach, which includes some indirect emission sources such as waste treatment not included in the other two studies. On the other hand, the differences between the top-down and bottom-up approaches may largely be due to the differences in data resolution, definition of urban, gases and sources included and the year of study. It is important to point out that we do not expect the top-down approach to be useful at the urban scale, as differences in the quality of infrastructure and intra-urban ranges cannot be captured. On the other hand, the top-down approach is helpful in generating data for a larger number of urban areas and at the regional and global scales the differences between the bottom-up and top-down estimates largely disappear.[54,55] Hence, while the top-down approach might be useful for policy at the

Table 5.2 Comparison of selected previous GHG results to our approach results for European urban areas (tons CO_2 equivalents).

Region/urban area	Country	Study date	Source	Total GHG emissions per capita	This study EDGAR-Total GHG emissions per capita
Southern Europe					
Athens	Greece	2005	Kennedy et al. 2009	10.4	3.9
Ancona	Italy	1998–2001	European Common Indicators, 2003	7.0	5.1
Bologna	Italy	2005	Kennedy et al. 2009	11.1	4.3
Catania	Italy	1995	European Common Indicators, 2003	5.0	5.4
Ferrara	Italy	1997	European Common Indicators, 2003	9.2	1.6
Naples	Italy	2005	Kennedy et al. 2009	4.0	5.5
Nord Milano	Italy	1998–2001	European Common Indicators, 2003	8.8	8.1
Parma	Italy	1998–2001	European Common Indicators, 2003	8.4	4.4
Pavia	Italy	1998–2001	European Common Indicators, 2003	6.0	2.9
Provincia Torino	Italy	1998–2001	European Common Indicators, 2003	7.6	8.4
Veneto	Italy	2005	Kennedy et al. 2009	10.0	10.2
Verbania	Italy	1998–2001	European Common Indicators, 2003	8.6	2.2
Porto	Portugal	2005	Kennedy et al. 2009	7.3	4.3
Ljubljana	Slovenia	2005	Kennedy et al. 2009	9.5	6.1
Maribor	Slovenia	1998–2001	European Common Indicators, 2003	8.7	4.7
A Coruña	Spain	1998–2001	European Common Indicators, 2003	7.1	5.9
Barcelona	Spain	1998–2001	European Common Indicators, 2003	3.6	4.9
Barcelona	Spain	2006	Kennedy et al. 2009	4.2	4.9
Burgos	Spain	1998–2001	European Common Indicators, 2003	8.0	5.3

Madrid	Spain	2005	Kennedy et al. 2009	6.9	5.8
Pamplona	Spain	1998–2001	European Common Indicators, 2003	3.5	5.4
Victoria-Gasteiz	Spain	1998–2001	European Common Indicators, 2003	7.2	4.0
Eastern Europe					
Blagoevgrad	Bulgaria	1998–2001	European Common Indicators, 2003	3.6	0.7
Prague	Czech Republic	2005	Kennedy et al. 2009	9.3	9.0
Gdansk	Poland	NA	European Common Indicators, 2003	6.9	6.1
Northern Europe					
Aarhus	Denmark	1998–2001	European Common Indicators, 2003	7.7	6.8
Helsinki	Finland	2005	Kennedy et al. 2009	7.0	9.8
Pori	Finland	1998–2001	European Common Indicators, 2003	11.9	16.8
Tampere	Finland	1998–2001	European Common Indicators, 2003	8.6	7.0
Turku	Finland	1998–2001	European Common Indicators, 2003	10.7	10.4
Oslo	Norway	1998–2001	European Common Indicators, 2003	2.5	7.6
Oslo	Norway	2005	Kennedy et al. 2009	3.5	7.6
Malmoe	Sweden	1998–2001	European Common Indicators, 2003	4.8	7.9
Stockholm	Sweden	2005	Kennedy et al. 2009	3.6	7.7
Stockholm	Sweden	1998–2001	European Common Indicators, 2003	3.9	7.7
Vaxjoe	Sweden	1998–2001	European Common Indicators, 2003	3.8	1.9
Bristol	United Kingdom	1998–2001	European Common Indicators, 2003	9.4	6.6
London	United Kingdom	2003	Kennedy et al. 2009	9.6	7.1
Glasgow	United Kingdom	2004	Kennedy et al. 2009	8.8	11.6

Table 5.2 *Continued*

Region/urban area	Country	Study date	Source	Total GHG emissions per capita	This study EDGAR-Total GHG emissions per capita
Western Europe					
Brussels	Belgium	2005	Kennedy et al. 2009	7.5	15.2
Paris	France	2005	Kennedy et al. 2009	5.2	7.6
Frankfurt	Germany	2005	Kennedy et al. 2009	13.7	2.5
Hamburg	Germany	2005	Kennedy et al. 2009	9.7	6.7
Stuttgart	Germany	2005	Kennedy et al. 2009	16.0	8.0
Geneva	Switzerland	2005	Kennedy et al. 2009	7.8	3.1
Average				*10.0*	*7.2*

Source: Kennedy et al. 2009, European Common Indicators 2003, this study.[56]

regional scale, it is not a substitute for intensive bottom-up studies upon which to base specific urban policy.

When compared to selected cities elsewhere,[57] the GHG emissions from urban areas in Europe demonstrate general patterns. Urban GHG emissions estimates for cities in North America are typically higher than those of Europe, with a regional average approximately double that found in Europe (Table 5.3). Indeed, only a few cities in Germany have estimated emissions levels falling within the range seen in the selected North American cities. Moreover, the GHG emissions estimates for European cities are considerably higher than for South American cities. Of the selected Asian urban areas, GHG emissions are typically higher than those in European urban centres with the exception of Tokyo, which falls within the range of estimates for European cities.

Comparison of our results with the other two efforts illustrates the difficulty of comparing individual city estimates calculated with different methodologies. For instance, only five of our city estimates fell within 10 per cent of published values from the other two reports: Catania (Italy), Milano (Italy), Prague (Czech Republic), Turku (Finland), and Veneto (Italy). The majority of city estimates in our sample fell within 50 per cent of the values published by the other reports, with a slight tendency to fall

Table 5.3 GHG emissions per capita from non-European Cities (tons CO_2 equivalents).

Urban area	Country	Study date	Total GHG emissions per capita
Denver	United States of America	2005	19.4
Los Angeles	United States of America	2000	13.0
New York City	United States of America	2005	10.5
Toronto	Canada	2005	11.6
Average			13.6
Rio de Janeiro	Brazil	1998	2.1
Sao Paulo	Brazil	2000	1.4
Average			1.8
Bangkok	Thailand	2005	10.7
Beijing	China	2006	10.1
Shanghai	China	2006	11.7
Tianjin	China	1998	11.1
Tokyo	Japan	2006	4.9
Average			9.7
Cape Town	South Africa	2006	7.6

Source: Kennedy et al. 2009.[58]

below the estimates published elsewhere. Yet three of our city estimates are more than double those found in the literature, for Brussels (Belgium), Oslo (Norway), and Stockholm (Sweden).

A significant amount of the discrepancy among the studies cited can be traced back to variations in study design (Kennedy et al. 2009, for example, is in itself a compilation of studies)[59] and inconsistencies with respect to the geographic boundaries studied and sources/gases included. The authors of this chapter examined the effect of different spatial definitions of 'urban' from high-density areas within the confines of legal boundaries and urbanised areas based on GRUMP boundaries[60] to extensive periurban inclusion areas with high intensity agriculture (especially Germany and Greece) and the majority of energy production (Plate 5b). Table 5.4 indicates the Europe-wide variation of the contribution of different emissions sources in three different definitions of the term 'urban'. Some emission sources, such as industrial production and transportation, are distributed in an intuitively understandable manner. Others, such as land use change, or agriculture and waste,

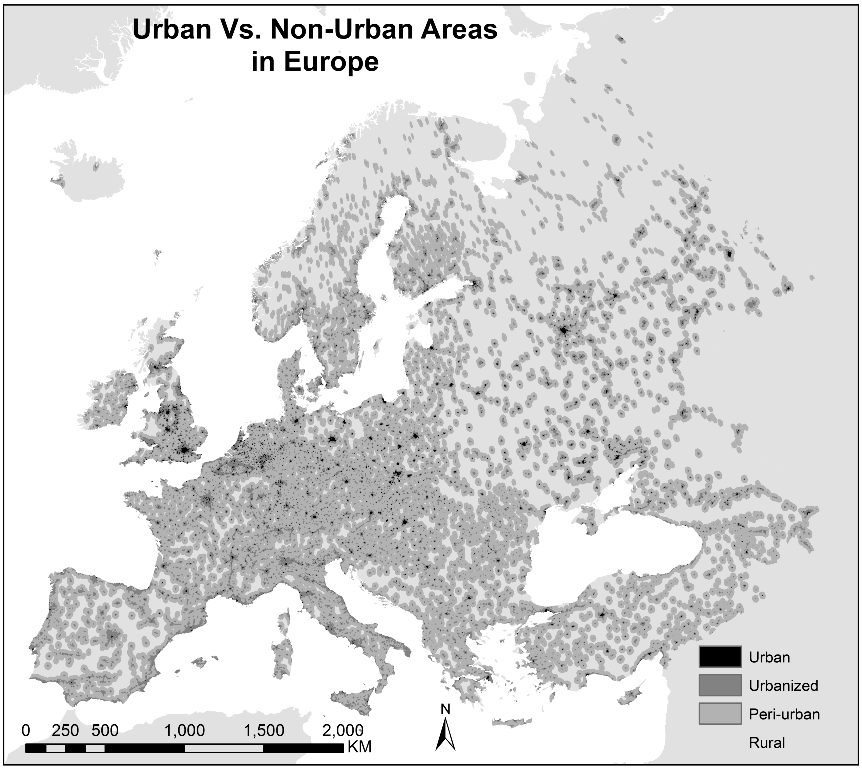

Figure 5.1 Extent of urban versus non-urban areas in Europe.
Source: the authors.

Table 5.4 Percentage of European GHG emissions by source in different definitions of urban areas.

Source	City Core	Urbanised	Periurban	Rural
Energy use in manufacturing and construction	14.6	49.9	31.6	3.9
Energy use in transportation	16.0	42.2	34.5	7.4
Energy use from other sources and fugitive emissions	12.9	31.2	44.0	11.9
Industrial processes	9.8	47.8	38.1	4.0
Agriculture	1.0	12.1	63.2	23.7
Land use change	1.6	10.2	69.1	19.2
Waste	11.4	37.6	40.8	10.1
Other anthropogenic sources	1.3	12.0	58.1	28.6
Total, Europe-wide	7.9	27.7	49.5	14.8

Source: this study.

have a surprisingly large impact in both the traditional metropolitan area and periurban context. These summary figures oscillate again widely when broken down into different countries/regions. Periurban land use change is the source of between 40 per cent and 78 per cent of all GHGs in that zone. In Slovenia, over 90 per cent of its industrial emissions originate outside metropolitan areas. Slovakia's urbanised areas contribute only 16 per cent of total GHG emissions in that country. It is therefore not surprising that the literature cited in this section seems so contradictory; the choices made with respect to geographic boundaries and included sources can have dramatic effects on final GHG estimates for urban areas.[61]

Discussion

Urban researchers have striven to develop rigorous protocols for standardising GHG emission estimates for policy and theoretical work. While there has been much progress, several drawbacks continue to plague this work and result in a general lack of comparability of findings across studies.[62,63] It is therefore not surprising that different inventory schemes produce disparate results.

More importantly, the differences in results reflect differences in the purposes for which the studies are produced. As noted by others, there are two types of studies on CO_2 emissions. One type of study inventories local emissions in single areas to directly support local policy objectives. They define detailed baselines that municipalities can use to judge performance. They are also awareness raising, educational, and participatory tools to facilitate increased understanding of and participation in lowering GHG emissions. The results from individual case studies reflect such detailed local context and knowledge, and are difficult to generalise to other urban areas. At the same time, the top-down approach is limited in that the resolution of the data is not fine enough to be of use at the urban scale.

Another type of study analyses a cross-section of localities to derive general relationships between energy use and patterns of urban development.[64] As such, these types of studies are useful for generating policy priorities at higher levels of governance (nations, regional international agreements). It is at this level that top-down analyses might be most useful. Regionally comparable studies of urban GHG emissions can identify 'outliers' for further examination with respect to policy decisions. They could point to those urban areas that may have policy or other actions that are lowering or increasing emissions. They also could be used to identify other influences on GHG emissions, including urban form, socio-economic characteristics, and biophysical context.

Given the different purposes for development of bottom-up individual case studies and top-down regional studies, we suggest that the findings from both types of analyses must be used together to support local and regional actions.[65] We also advise the continued development of rigorous protocols for estimating comparable GHG emissions from urban areas worldwide, which would both advance our scientific knowledge as well as aid in identification of mitigation potentials and priorities.

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