CHAPTER 3

THE CONTRIBUTION OF URBAN AREAS TO CLIMATE CHANGE

The allocation of responsibility for greenhouse gas (GHG) emissions – and, hence, climate change – is an important global policy debate. Indeed, the importance of responsibility is explicitly recognized in the United Nations Framework Convention on Climate Change (UNFCCC) allocation of 'common but differentiated responsibilities' among countries for addressing emissions.[1] As shown in Chapter 1, urban areas – which are now home to more than half of the world's population – clearly have an important role to play in facilitating reduced emissions; yet the contribution of urban areas to emissions is often unclear.

There are several reasons why it is important to consider the contribution of urban areas to climate change. *First*, a range of activities are associated with cities and their functioning that contribute to GHG emissions. Transportation, energy generation and industrial production within the territorial boundaries of towns and cities generate GHG emissions directly. Urban centres rely on inward flows of food, water and consumer goods that may result in GHG emissions from areas outside the city. In addition, individuals consume a range of goods and services that may have been produced locally or outside the urban area. An analysis of the relative impacts of these activities is an important step towards understanding the extent of the contribution of urban areas to climate change.

Second, measuring emissions from different cities provides a basis for comparisons to be made and the potential for inter-urban competition and cooperation. Climate-friendly development has the potential to attract external investment, and the growing importance of international urban networks[2] provides spaces for learning and knowledge sharing. Emissions measuring has recently been inserted into global policy debates. For example, the United Nations Environment Programme (UNEP), the United Nations Human Settlements Programme (UN-Habitat) and the World Bank launched an International Standard for Determining Greenhouse Gas Emissions for Cities at the World Urban Forum in Rio de Janeiro in March 2010.[3] This standard provides a common method for cities to calculate the amount of GHG emissions produced within their boundaries.

Third, an assessment of the contribution of cities to climate change is a vital first step in identifying potential solutions. The large and growing proportion of the Earth's population living in towns and cities, and the concentration of economic and industrial activities in these areas, means that they need to be at the forefront of mitigation. The establishment of emission baselines is necessary if effective mitigation benefits are to be identified and applied.

Finally, it is important to highlight the differences between *production*- and *consumption*-based analyses of GHG emissions. Most assessments of the contribution of cities – and countries – to climate change have focused on the emissions that are produced by activities taking place within given territorial boundaries. However, an alternative approach is to consider the emissions associated with the consumption patterns of individuals, recognizing that many agricultural and manufacturing activities that meet the needs of urban residents take place outside city boundaries, and often in other countries. This consumption-based approach provides an alternative framework for suggesting appropriate ways of reducing GHG emissions by focusing on consumer choices as potential drivers for mitigation.

The first two sections of this chapter explain the scientific and technical basis for measuring GHG emissions from urban areas. The third section presents findings from a wide range of urban emissions inventories to show how these vary from place to place, while the fourth section describes the factors influencing emissions at the urban level. Finally, the chapter examines different approaches to measuring GHG emissions and shows that the simple analyses that have been frequently used until now are no longer sufficient for addressing this urgent global challenge.

MEASURING GREENHOUSE GAS EMISSIONS

In order to account for the contribution of urban areas to climate change, it is necessary to measure their emissions of GHGs.[4] This requires particular methodologies to account for the various activities and the volume of these gases that they produce. And in order to make meaningful comparisons over time, or between different places, there is a need for standardized protocols to be developed. According to the UNFCCC, inventories should meet the following five quality criteria:[5]

The allocation of responsibility for greenhouse gas … emissions – and, hence, climate change – is an important global policy debate

Climate-friendly development has the potential to attract external investment

the … International Standard for Determining Greenhouse Gas Emissions for Cities … provides a common method for cities to calculate the amount of GHG emissions produced within their boundaries

1 *Transparency:* assumptions and methodologies should be clearly explained.
2 *Consistency:* the same methodology should be used for base and subsequent years.
3 *Comparability:* inventories should be comparable between different places.
4 *Completeness:* inventories should cover all relevant sources of emissions.
5 *Accuracy:* inventories should be neither over nor under true emissions.

The UNFCCC is the global instrument responsible for ensuring that countries measure national GHG emissions and set targets for their reduction

International protocols for measuring greenhouse gas emissions

As noted in Chapter 2, the UNFCCC is the global instrument responsible for ensuring that countries measure national GHG emissions and set targets for their reduction. Under the Convention, national governments gather and share information on GHG emissions; launch national strategies to reduce emissions; and cooperate to prepare for adaptation to climate change impacts. A total of 36 developed countries have – under the Kyoto Protocol – accepted emission 'caps' that limit their total GHG emissions within a designated timeframe and are required to submit annual inventories of their national emissions, while other signatories to the Kyoto Protocol submit emission inventories in their periodic national communications.

National inventories are prepared according to a detailed set of criteria developed by the Intergovernmental Panel on Climate Change (IPCC): the *IPCC Guidelines for National Greenhouse Gas Inventories*.[6] This is a detailed series of five volumes prepared by the IPCC as a result of a request by the UNFCCC. It is intended to ensure that countries are able to fulfil their commitments under the Kyoto Protocol and subsequent international agreements. These criteria recognize that figures will be estimates, but seek to ensure that these do not contain any biases that could have been identified and eliminated. There are also different tiers of estimation methods, which take into account varying availability of data between countries. The inventories provide measuring strategies and global warming potentials for the full range of GHGs, and include methodologies for estimating emissions in four key sectors. These are: energy; industrial processes and product use; agriculture, forestry and other land use; and waste (see Table 3.1).

In the case of urban areas, emissions from the use of fossil fuels, industrial processes and product use, and waste are of particular importance. Stationary combustion mainly relates to energy industries, manufacturing industries and construction; while mobile combustion includes transportation emissions from civil aviation, road transportation, railways and waterborne navigation (although only within national boundaries – fuel use associated with international maritime transportation is not included). These distinctions are important, as – taken as a whole – energy, transportation and buildings account for almost half of all global emissions (see Figures 1.4 and 3.1).

National GHG inventories are based on the assumption that a country is responsible for all emissions produced within its area of jurisdiction. As a pragmatic measure to facilitate national targets and reductions, this is likely to be the only enforceable strategy – as countries only have legislative power within their own national boundaries. However, it means that the patterns of consumption that drive emissions (notably in the energy and industry sectors) are often veiled. For example, many polluting and carbon-intensive manufacturing processes are no longer located in developed countries, but have been sited elsewhere in the world to take advantage of lower labour costs and less rigorous environmental enforcement, and this reduces emissions in developed countries.[7] This is an important issue when assessing the underlying factors influencing emissions, which is discussed later in this chapter.[8]

Table 3.1

Sectors assessed for national GHG inventories

Sector	Sub-sectors
Energy	Stationary combustion Mobile combustion Fugitive emissions CO_2 transport, injection and geological storage
Industrial processes and product use	Mineral industry emissions Chemical industry emissions Metal industry emissions Non-energy products from fuels and solvent use Electronics industry emissions Emissions of fluorinated substitutes for ozone-depleting substances Other product manufacture and use
Agriculture, forestry and other land use	Forest land Cropland Grassland Wetlands Settlements Other land Emissions from livestock and manure management Nitrous oxide emissions from managed soils, and CO_2 emissions from lime and urea application Harvested wood products
Waste	Solid waste disposal Biological treatment of solid waste Incineration and open burning of waste Wastewater treatment and discharge

Note: The GHGs to be assessed are CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, nitrogen trifluoride, trifluoromethyl sulphur pentafluoride, halogenated ethers and other halocarbons (see also Table 1.3).

Source: IPCC, 2006

Protocols for measuring corporate greenhouse gas emissions

As industries and corporations have become increasingly aware of the impact that their activities have upon the environment, they have increasingly engaged in conducting GHG inventories. This enables companies to develop effective strategies to manage and reduce GHG emissions, and to facilitate their participation in voluntary and mandatory emissions reductions programmes. The most frequently utilized of these is the Greenhouse Gas Protocol developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). This protocol puts forward an accounting system that is based on relevance, completeness, consistency, transparency and accuracy, and provides a mechanism by which private-sector actors can contribute to the global goal of reducing GHG emissions.[9]

Table 3.2

Emissions scopes for companies

Sector	Definition	Examples
Scope 1:	Direct GHG emissions that occur from sources owned or controlled by the company.	Emissions from combustion in owned or controlled boilers, furnaces, vehicles; emissions from chemical production in process equipment.
Scope 2:	GHG emissions from the generation of purchased electricity consumed by the company.	Purchased electricity in which the emissions physically occur at the facility where electricity is generated.
Scope 3 (optional):	GHG emissions that are a consequence of the activities of the company, but occur from sources not owned or controlled by the company.	Extraction and production of purchased materials; transportation of purchased fuels; use of sold products and services.

Source: WRI/WBCSD, undated

The protocol addresses the issues peculiar to the corporate sector of accounting for emissions from group companies, subsidiaries, affiliated companies, non-incorporated joint ventures or partnerships, fixed-asset investments and franchises. The concept of '*scope*' was developed in this process,[10] which takes into account direct and indirect GHG emissions in a more effective manner (see Table 3.2). It also describes the processes by which GHG emissions can be identified and calculated, how these can be verified for a formal reporting process, and how targets can be set.

Protocols for measuring local government greenhouse gas emissions

Urban authorities often function at two distinct levels. First, they function as *business enterprises* – owning or leasing buildings, operating vehicles, purchasing goods and carrying out various other activities. In this regard, urban authorities can assess their emissions as corporate entities, including the direct and indirect impacts of their work. Second, urban authorities function as *governments* – with varying levels of oversight for and influence on the activities taking place within the spatial area over which they have jurisdiction.

The most widely accepted methodology for measuring emissions within local government boundaries has been developed by Local Governments for Sustainability (ICLEI), which is an international association of more than 1000 local government authorities that have made a commitment to sustainable development. More than 700 of these are members of the Cities for Climate Protection Campaign (see Box 2.7), which aims to assist cities in adopting policies to reduce local GHG emissions, improve air quality, and improve urban liveability and sustainability. The campaign sets five milestones for participating authorities:

1 Conduct a baseline emissions inventory and forecast.
2 Adopt an emission reduction target for the forecast year.
3 Develop a local action plan.
4 Implement policies and measures.
5 Monitor and verify results.[11]

The first stage of this process requires an emissions inventory; yet no appropriate methodology existed when the campaign was devised. The IPCC methodology for countries does not provide specifications at the local authority level for discussing energy consumption, transportation or waste disposal; and the existing corporate accounting protocols do not cover the details of municipal operations such as street lighting, landfill emissions and emissions from wastewater treatment or other industrial activities.

ICLEI's International Local Government GHG Emissions Analysis Protocol[12] was developed in response to this need. This protocol takes into account both government and community sectors, using the main categories derived from the IPCC's guidelines on national inventories of GHG emissions from stationary combustion, mobile combustion, fugitive emissions,[13] product use, other land use and waste. The protocol organizes government emissions according to:

- buildings and facilities;
- electricity or district heating/cooling generation;
- vehicle fleet;
- street lighting and traffic signals;
- water and wastewater treatment, collection and distribution;
- waste;
- employee commute;
- others.

The most widely accepted methodology for measuring emissions within local government boundaries has been developed by Local Governments for Sustainability (ICLEI)

It also breaks down the 'macro-sectors' used by the IPCC methodology (shown in Table 3.1) into community sectors for analysis, as shown in Table 3.3. ICLEI's framework provides the basis for the calculation of most current city-wide GHG emissions inventories.[14] It also recognizes the concept of *scopes*[15] in both government and community sectors (see Table 3.4). However, these do not extend as far as the consumption-based approaches,[16] many of which are impractical given the financial and technical resources available to local authorities to conduct inventories of this type. A more detailed consumption-based analysis requires much more information relating to the embedded carbon content of consumer goods purchased by individuals.

Table 3.3

ICLEI categorization of community sectors

Macro-sector (IPCC)		Community sector (ICLEI)
Energy	Stationary combustion	Residential
		Commercial
		Industrial
	Mobile combustion	Transportation
	Fugitive emissions	Other
Industrial processes and product use		Other
Agriculture, forestry and other land use		Agricultural emissions
		Other
Waste	Solid waste disposal	Waste
	Biological treatment of solid waste	
	Incineration and open burning of waste	
	Wastewater treatment and discharge	

Source: ICLEI, 2008

Table 3.4

Emissions scopes for local authorities

	Definitions	Examples
Government operations emissions:		
Scope 1:	Direct emission sources owned or operated by the local government.	A municipal vehicle powered by gasoline or a municipal generator powered by diesel fuel.
Scope 2:	Indirect emission sources limited to electricity, district heating, steam and cooling consumption.	Purchased electricity used by the local government, which is associated with the generation of GHG emissions at a power plant.
Scope 3:	All other indirect or embodied emissions over which the local government exerts significant control or influence.	Emissions resulting from contracted waste-hauling services.
Community-scale emissions:		
Scope 1:	All direct emissions sources located within the geopolitical boundary of the local government.	Use of fuels such as heavy fuel oil, natural gas or propane used for heating.
Scope 2:	Indirect emissions that result as a consequence of activity within the jurisdiction's geopolitical boundary limited to electricity, district heating, steam and cooling consumption.	Purchased electricity used within the geopolitical boundaries of the jurisdiction associated with the generation of GHGs at the power plant.
Scope 3:	All other indirect and embodied emissions that occur as a result of activity within the geopolitical boundary.	Methane emissions from solid waste generated within the community which decomposes at landfills either inside or outside of the community's geopolitical boundary.

Source: compiled from ICLEI, 2008

New baseline inventories for urban emissions

A … consumption-based analysis requires much more information relating to the embedded carbon content of consumer goods purchased by individuals

Increased interest in the contribution of urban areas to GHG emissions, and a growing recognition of the importance of urban areas in addressing the causes of climate change, means that there have been increasing attempts to develop appropriate inventories to account for city-level emissions. Many of these now grapple with complex issues of production- and consumption-based measures for allocating emissions.[17] An important component of these inventories is the setting of baselines, which can then be used to set targets for emissions reductions in subsequent years. It is also possible that a widely accepted baseline methodology might form the basis for emissions trading schemes, or for urban areas as a whole to trade carbon credits either on the formal or the voluntary market.[18] Table 3.5 presents a World Bank compilation of GHG emission baselines for selected cities and countries.

In addition, the recently launched International Standard for Determining Greenhouse Gas Emissions for Cities[19] provides a common method for cities to calculate the amount of GHG emissions produced within their boundaries. This standard builds on and is consistent with the IPCC protocols for national governments, and provides a common format to facilitate compilation by local authorities. It is hoped that this will provide a standard that can be used by cities around the world.

Boundary issues

Efforts to develop a … methodology for GHG emissions at the local or municipal level are made more complicated by the wide range of boundary definitions used for these areas

Efforts to develop a standardized globally comparable methodology for GHG emissions at the local or municipal level are made more complicated by the wide range of boundary definitions used for these areas. In general, the smaller the scale, the greater the challenges posed by 'boundary problems' in which it is increasingly difficult to identify which emissions ought or ought not to be allocated to a particular place.[20]

The importance of boundary definitions is clear from studies of urban populations, where differences in how governments define city boundaries have direct effects of spatial structure. For instance, it has been shown how eight different lists of the world's 20 largest cities vary, with only nine cities appearing on all eight lists; and with four different areas competing for the first two ranks.[21] The population figures for some large cities are for people living within long-established city boundaries enclosing areas of only 20 to 200 square kilometres; whereas for others (particularly in China) this includes regions with many thousands of square kilometres and a significant rural population.[22] These complications – related to different definitions of *cities and urban areas*, and different conceptions of the spatial extent of these – are all equally relevant in relation to identifying GHG emissions from a particular urban area. Similarly, energy consumption in *urban areas* in the US can vary between 37 and 81 per cent depending on how these areas are defined and bounded in space.[23] Thus, even within a single country, the potential contribution of urban areas to climate change can vary by a factor of two depending on the spatial definition of these areas.[24]

THE SOURCES OF GREENHOUSE GAS EMISSIONS

Towns and cities do not themselves emit GHGs. Rather, specific activities that take place within urban areas … are the sources of these GHGs

Towns and cities do not themselves emit GHGs. Rather, specific activities that take place within urban areas – and that are undertaken in different ways by people of different ages, genders and income groups – are the sources of these GHGs. Different activities or sectors emit different quantities of different gases – with diverse impacts upon climate change (see Figure 3.1). Some of these activities have been integral to the process of urbanization over the last 300 years, and some have the clear potential to reduce emissions to mitigate climate change.

The main sources of GHG emissions from urban areas are related to the consumption of fossil fuels: whether this is for electricity supply, transportation or industry. This section explores the main sources of GHG emissions from urban

Table 3.5

Representative GHG baselines for selected cities and countries

Country	Annual GHG emissions (tonnes of CO_2eq per capita)	Year	City	Annual GHG emissions (tonnes of CO_2eq per capita)	Year
Argentina	7.64	2000	Buenos Aires	3.83	
Australia	25.75	2007	Sydney	0.88	2006
Bangladesh	0.37	1994	Dhaka	0.63	
Belgium	12.36	2007	Brussels	7.5	2005
Brazil	4.16	1994	Rio de Janeiro	2.1	1998
			São Paulo	1.4	2000
Canada	22.65	2007	Calgary	17.7	2003
			Toronto (City of Toronto)	9.5	2004
			Toronto (Metropolitan Area)	11.6	2005
			Vancouver	4.9	2006
China	3.40	1994	Beijing	10.1	2006
			Shanghai	11.7	2006
			Tianjin	11.1	2006
			Chongqing	3.7	2006
Czech Republic	14.59	2007	Prague	9.4	2005
Finland	14.81	2007	Helsinki	7.0	2005
France	8.68	2007	Paris	5.2	2005
Germany	11.62	2007	Frankfurt	13.7	2005
			Hamburg	9.7	2005
			Stuttgart	16.0	2005
Greece	11.78	2007	Athens	10.4	2005
India	1.33	1994	Ahmedabad	1.20	
			Delhi	1.50	2000
			Kolkata	1.10	2000
Italy	9.31	2007	Bologna (Province)	11.1	2005
			Naples (Province)	4.0	2005
			Turin	9.7	2005
			Veneto (Province)	10.0	2005
Japan	10.76	2007	Tokyo	4.89	2006
Jordan	4.04	2000	Amman	3.25	2008
Mexico	5.53	2002	Mexico City (City)	4.25	2007
			Mexico City (Metropolitan Area)	2.84	2007
Nepal	1.48	1994	Kathmandu	0.12	
The Netherlands	12.67	2007	Rotterdam	29.8	2005
Norway	11.69	2007	Oslo	3.5	2005
Portugal	7.71	2007	Porto	7.3	2005
Republic of Korea	11.46	2001	Seoul	4.1	2006
Singapore	7.86	1994			
Slovenia	10.27	2007	Ljubljana	9.5	2005
South Africa	9.92	1994	Cape Town	11.6	2005
Spain	9.86	2007	Barcelona	4.2	2006
			Madrid	6.9	2005
Sri Lanka	1.61	1995	Colombo	1.54	
			Kurunegala	9.63	
Sweden	7.15	2007	Stockholm	3.6	2005
Switzerland	6.79	2007	Geneva	7.8	2005
Thailand	3.76	1994	Bangkok	10.7	2005
UK	10.50	2007	London (City of London)	6.2	2006
			London (Greater London Area)	9.6	2003
			Glasgow	8.8	2004
US	23.59	2007	Austin	15.57	2005
			Baltimore	14.4	2007
			Boston	13.3	
			Chicago	12.0	2000
			Dallas	15.2	
			Denver	21.5	2005
			Houston	14.1	
			Philadelphia	11.1	
			Juneau	14.37	2007
			Los Angeles	13.0	2000
			Menlo Park	16.37	2005
			Miami	11.9	
			Minneapolis	18.34	2005
			New York City	10.5	2005
			Portland, OR	12.41	2005
			San Diego	11.4	
			San Francisco	10.1	
			Seattle	13.68	2005
			Washington, DC	19.70	2005

Note: Sources of the data presented above and details on which emissions have been included in the baselines are specified in the original source.

Source: based on World Bank, undated c

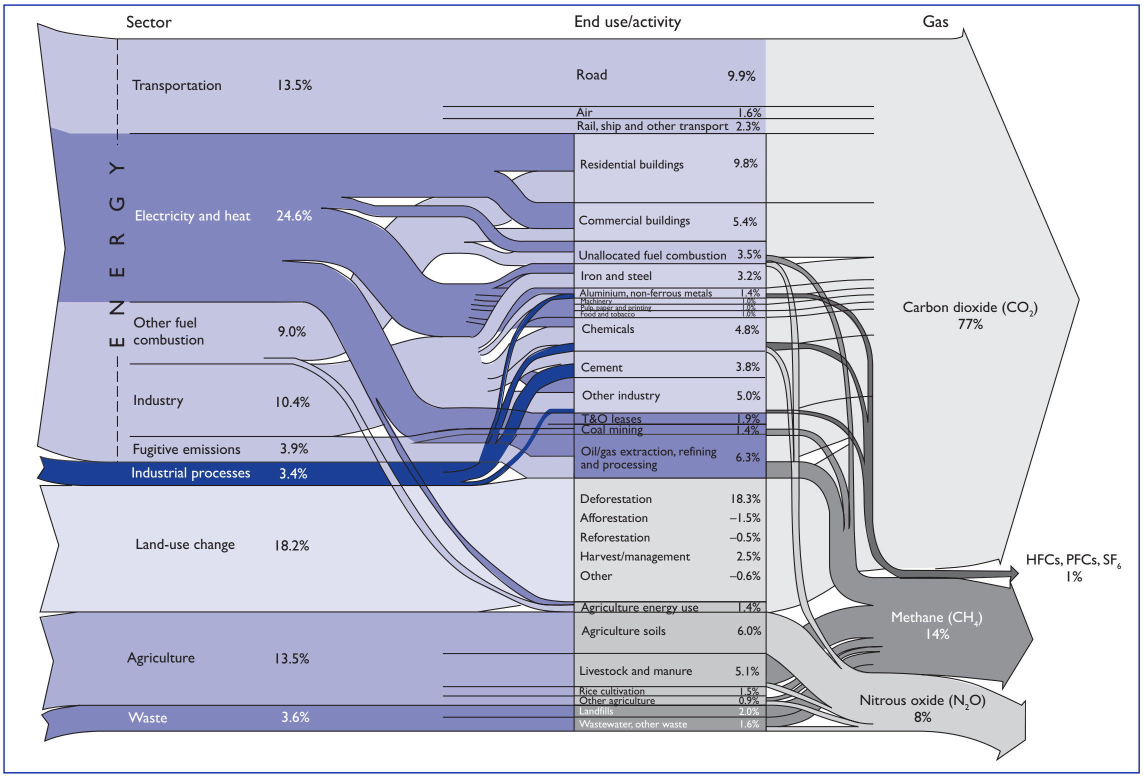


Figure 3.1

Global GHG emissions by sector and end use/activity

Notes: All data are for 2000. All calculations are based on CO_2eq, using 100-year global warming potentials based on an IPCC total global estimate of 41,755 million tonnes CO_2eq. Land-use change includes both emissions and absorptions. Dotted lines represent flows of less than 0.1 per cent of total GHG emissions.

Source: World Resources Institute (http://cait.wri.org/figures/World-FlowChart.pdf)

areas, with a focus on energy supply (for electricity generation, transportation, commercial and residential buildings), industry, waste, agriculture, land-use change and forestry. It examines the activities that contribute to GHG emissions from these sectors, the types of gases that are generated and the importance of these for climate change. It also highlights the potential for mitigation in each of these sectors, setting the stage for detailed discussion in Chapter 5.

Energy supply for electricity generation

Energy is perhaps the broadest possible category for assessing GHG emissions. The combustion of fossil fuels is the major source of these, and is used throughout the world for electricity generation, heating, cooling, cooking, transportation and industrial production. Energy is obtained from fossil fuels, biomass, nuclear power, hydroelectric generation and other renewable sources. Urban areas rely heavily on energy systems (shaped by the quantity of energy used), the energy structure (types of energy forms used) and the quality of the energy (its energetic and environmental characteristics). This section will thus focus on the use of energy for electri-city generation in urban areas, the different sources of energy and the implications for GHG emissions. Overall (in 2008), transport accounted for approximately 1.6 per cent of global electricity use; industry accounted for 41.7 per cent; while other sectors (agriculture, commercial and public services, residential, and non-specified other sectors) accounted for 56.7 per cent.[25] The particular aspects of electricity consumption by industry, and in commercial and residential buildings, will be examined later in this section.

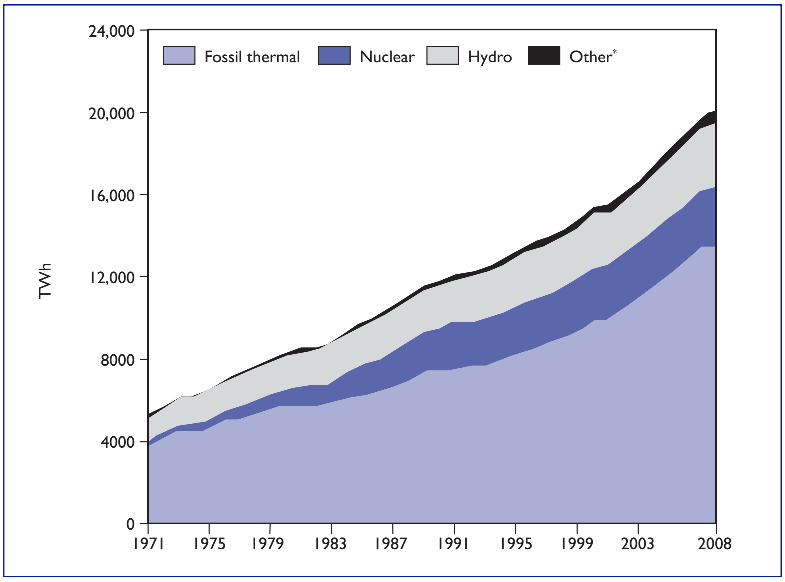
Electricity functions as an 'energy carrier' – that is, an intermediate step between the original source of energy and the end user. In concentrated and densely populated urban areas, electricity is much more practical than the more direct use of fuels, particularly because large generation plants can be located hundreds of kilometres away and can feed electricity grids covering large areas. In 2008, a total of 20,181 terawatt hours (TWh) of electricity were produced around the world, most of which was generated from thermal energy (fossil fuels of oil, coal and gas) (see Figure 3.2 and Table 3.6). The world has a continued dependence on these GHG-generating fuels. Although the relative reliance on fossil fuels for electricity generation declined from 75.1 per cent in 1973 to 67.7 per cent in 2008, the total amount of energy produced from these sources grew from 4593TWh to 13,675TWh over the same period – recording an increase of 197.7 per cent.[26] The IPCC Fourth Assessment Report concluded that 'the global energy supply

Figure 3.2

World electricity generation by fuel type (1971–2008)

Note: 'Other' includes geothermal, solar, wind, combustible renewables and waste, and heat.

Source: IEA, 2010, p24



will continue to be dominated by fossil fuels for several decades'[27] and projected that without the introduction of effective new policy actions, energy-related GHG emissions are expected to rise by over 50 per cent between 2004 and 2030 (from 26.1 billion tonnes CO_2eq to between 37 and 40 billion tonnes CO_2eq).[28]

Electricity consumption varies significantly between urban areas around the world, although there is some clustering in the region of 4.5 to 7MWh per capita per annum for those connected to the grid: Bangkok (Thailand), Barcelona (Spain), Geneva (Switzerland), London (UK), Los Angeles (US), New York City (US) and Prague (Czech Republic) all fall within this range. In contrast, Cape Town (South Africa) has considerably lower per capita consumption (3.49MWh per capita per annum – perhaps because a large proportion of the population is not connected to electricity supply); while Toronto (Canada) and Denver (US) have considerably higher per capita consumption of 10.04 and 11.49MWh per capita per annum, respectively.[29]

The type of fuel used to generate electricity has a significant impact upon the volume of GHG emissions. Indeed, this is one of the most striking features influencing the emissions from different areas. Cities relying on nuclear or hydroelectric power generate substantially lower emissions than those that depend primarily on coal-fired power stations.[30]

In countries relying heavily on coal for electricity generation, electricity can be the single largest contributor to GHG emissions. A study of 15 South African cities indicated that electricity generation was responsible for more than 100 million tonnes of CO_2 emissions annually, or 66 per cent of the total – despite accounting for only 32 per cent of energy consumption.[31] However, average figures for electricity consumption – and the GHG emissions relating to these – are problematic because of industrial use of electricity. More detailed surveys are required to identify which members of society are utilizing large quantities of electricity and, thus, are responsible for the accompanying GHG emissions. In China, although the direct use of coal for energy has declined substantially during the last two decades, this remains the majority source for the generation of electricity.[32]

Among fossil fuels there are differences in the emissions generated for a given unit of electricity. Although coal is the world's most abundant fossil fuel and continues to be a vital resource in many countries, the typical efficiency of its conversion into electricity is about 35 per cent; and the burning of coal introduced approximately 9.2 billion tonnes of CO_2 into the atmosphere in 2005. The use of natural gas for electricity generation is growing rapidly (at an annual rate of 2.3 per cent during the 1990s), and contributes around 5.5 billion tonnes of CO_2 into the atmosphere each year. In contrast, the use of oil for direct generation of electricity has declined during recent years.[33] The operation of nuclear generation plants generates very low emissions of GHGs, although large indirect emissions are associated with the mining (and refining) of uranium and the building of nuclear plants.[34] This source of energy, however, has risks associated with its operation, storage of waste and the generation of materials that can be used in nuclear weapons. For these reasons, public acceptance of nuclear power is limited in many countries.[35]

A variety of renewable energy systems can contribute to the security of energy supply and the reduction in GHG emissions (see Table 3.7).[36] However, there are still many challenges to be overcome in relation to the development of these technologies and in ensuring consistency in their generation capacity. For example, energy available from solar, wind and wave energy varies over time.

Many developing countries still face considerable challenges in expanding electricity networks to households – with low-income and female-headed households particularly seriously affected. In South Africa, for example, 64 per cent of the total population has no access to grid electricity. Although this is higher in rural areas, 16 per cent of households in cities did not use electricity for lighting.[37] Drawing on data for urban populations from a range of sources, it has been estimated that among the 117 developing countries for

Table 3.6

Electricity generation by energy source

Type of fuel	Share of total energy generation (%) 1973 (total generation: 6116TWh)	2008 (total generation: 20,181TWh)
Thermal	75.1	67.8
Coal/peat	38.3	41.0
Oil	24.7	5.5
Gas	12.1	21.3
Nuclear	3.3	13.5
Hydro	21.0	15.9
Other (geothermal, solar, wind, combustible renewable and waste, heat)	0.6	2.8

Source: IEA, 2010, p24

The type of fuel used to generate electricity has a significant impact upon the volume of GHG emissions

Table 3.7

Categories of renewable energy technologies

Examples of technology	Stage of maturity
Large and small hydro Woody biomass combustion Geothermal Landfill gas capture Crystalline silicon photovoltaic solar-water heating Onshore wind Bio-ethanol from sugars and starch	Technologically mature with established markets in several countries.
Municipal solid waste to energy Anaerobic digestion Biodiesel Co-firing of biomass Concentrating solar dishes and troughs Solar-assisted air conditioning Mini- and micro-hydro Offshore wind	Technologically mature but with relatively new and immature markets in a small number of countries.
Thin-film photovoltaic Concentrating photovoltaic Tidal range and currents Wave power Biomass gasification and pyrolysis Bio-ethanol from ligno-cellulose Solar thermal towers	Under technological development with demonstrations or small-scale commercial application, but approaching wider market introduction.
Organic and inorganic nanotechnology solar cells Artificial photosynthesis Biological hydrogen production involving biomass, algae and bacteria Bio-refineries Ocean thermal and saline gradients Ocean currents	Still in technology research stages.

Source: compiled from Sims et al, 2007 which data were available, there were 21 countries where more than half of urban households did not have access to electricity. Furthermore, there seems to be a strong correlation between the proportion of the urban population who have access to electricity and gross domestic product (GDP).[38] Increasing low-income urban residents' access to electricity generates important improvements to quality of life, including through reducing the use of potentially harmful or dangerous alternative fuels for heating, lighting and cooking. The provision of energy services – including electricity – is therefore an important component of alleviating poverty.

The proportion of journeys made by private as opposed to public transportation ... is an important factor influencing GHG emissions from an urban area

Transport[39]

Globally, transportation is responsible for about 23 per cent of total energy-related GHG emissions[40] and 13 per cent of global GHG emissions (see Figure 1.4). In addition, transport activities increase as economies grow, and are expected to continue increasing in the decades ahead, especially with increasing levels of urbanization. Urban areas rely heavily on transportation networks of various kinds for both internal and external movements of goods and people. The proportion of journeys made by private as opposed to public transportation – particularly in larger cities – is an important factor influencing GHG emissions from an urban area. Urban areas, particularly in developed countries, often generate smaller amounts of GHG emissions per capita than rural areas due to the advantages of density. In the US, for example, per capita gasoline consumption is 12 per cent lower in urban counties than the national average.[41] Increases in public transportation use tend to reduce GHG emissions. A recent study suggested that a 1 per cent increase in public transportation would lead to a 0.48 per cent decrease in GHG emissions.[42]

Innovative thinking in relation to the planning of transportation infrastructure can ... meet both environmental and social needs

Urban density is one of the most important factors influencing the amount of energy used in private passenger transport, and therefore has a significant effect on GHG emissions. Table 3.8 shows the ranking of ten cities on the basis of private passenger energy use, urban density and GHG emissions. With the exception of the Chinese cities, the most densely populated cities utilize less energy for private passenger transport and generally have lower GHG emissions per capita.

Table 3.8

Private passenger transport energy use, urban density and GHG emissions, selected cities

Private passenger transport energy per person (ascending order)	Urban density (descending order)	GHG emissions per capita (ascending order)
Shanghai (China)	Seoul	São Paulo
Beijing (China)	Barcelona	Barcelona
Barcelona (Spain)	Shanghai	Seoul
Seoul (Republic of Korea)	Beijing	Tokyo
São Paulo (Brazil)	Tokyo	London
Tokyo (Japan)	São Paulo	Beijing
London (UK)	London	New York City
Toronto (Canada)	Toronto	Shanghai
New York (US)	New York	Toronto
Washington, DC (US)	Washington, DC	Washington, DC

Source: compiled from Newman, 2006

Access to public transport need not necessarily imply high density, as shown by the concepts of 'transit-oriented development' and 'transit villages' pioneered in California (US). These forms of development utilize moderate- to high-density housing within easy walking distance of major transit stops. However, this also requires careful planning of transit systems, the formation of community partnerships, detailed understanding of local real estate markets, and coordination among local, national and regional authorities. If successful, these developments can provide mobility choices, increase public safety, reduce the number of vehicle kilometres travelled (lowering annual household rates of driving by 20 to 40 per cent for those living, working and/or shopping near transit stations), reduce air pollution, reduce energy consumption, conserve resource lands and open space, reduce infrastructure costs, and contribute to more affordable housing.

Similar processes can be facilitated through the development of bus rapid transit systems in developing countries, which is discussed in more detail in Chapter 5. These are most efficient in servicing densely populated linear developments, which facilitate a large number of urban residents living within walking distances of the main trunk routes – generating an urban form often described as being shaped like a hand with fingers (where the 'palm' is the urban centre, and the 'fingers' the linear densely settled areas spreading out from the core).

Innovative thinking in relation to the planning of transportation infrastructure can therefore meet both environmental and social needs. Localized areas of relatively high densities are required to generate greater efficiencies in the usage of public transportation; but this can be consistent with meeting a variety of other demands from urban residents. Of course, the precise form that these transportation networks should take requires detailed local study. Overall, density is one of several factors that affects energy use – and, by extension, GHG emissions. However, addressing these issues requires ongoing analysis of urban *processes* rather than simply taking a snapshot of urban *form* at a particular moment in time.

A key component of GHG emissions from transportation is the number of vehicle kilometres travelled. The number of vehicle kilometres travelled is affected by several key aspects of urban design, including:

- density (higher number of people, jobs and/or dwelling units per unit area);
- diversity (greater mix of land uses);
- design (smaller block sizes, more sidewalk coverage, smaller street width);
- destination accessibility; and
- distance to transit.[43]

These 'five Ds' can be affected by the choices of planners and developers, and, in turn, will affect the travel choices of residents living in these areas. These aspects of urban design intersect with issues of personal choice and economic necessity – for example, there is some evidence from Sweden that women are more likely to use public transportation than men.[44] Chapter 5 shows the ways in which efficient urban design – including the use of brownfield developments – can help to minimize the distances that urban residents have to travel and, hence, reduce GHG emissions.

However, a variety of other factors also affect emissions from ground transportation, including the extent of private motor vehicle use, the quality of public transport, land-use planning and government policy. As shown in Table 3.9, there are significant variations between North American cities as a result of these factors. For example, Denver's per capita GHG emissions from ground transportation are four times greater than those of New York. Similarly, the high level of private motor vehicle dependence in Bangkok means that its per capita emissions from ground transportation are twice those of London, a much more affluent city but one with a more comprehensive public transportation system.

These variations can also be seen in the proportion of a city's GHG emissions that can be attributed to the transport sector. Shanghai and Beijing generate approximately 11 per cent of their emissions from the transportation sector, a figure dwarfed by their emissions from manufacturing.[45] However, the emissions from transport are increasing rapidly in Chinese cities, as shown by a recent study. The CO_2 emissions from transport in all 17 sample cities increased between 1993 and 2006. On average, the increase between 2002 and 2006 was 6 per cent per year and ranged from 2 to 22 per cent between the sample cities. The CO_2 emissions per capita from transport also increased in all cities and ranged between 0.5 and 1.4 tonnes per person in 2006, with Beijing being the highest.[46]

In London, New York and Washington, DC, transportation represents a significant contribution to the cities' emissions (22, 23 and 18 per cent, respectively); whereas in Barcelona (35 per cent), Toronto (36 per cent), Rio de Janeiro (30 per cent) and São Paulo (60 per cent), these figures are much higher.[47] However, the high figures in Rio de Janeiro and São Paulo are partially because these cities are strongly reliant on private motor vehicle transportation At the same time, it should be noted that London's emissions from transportation are lower than most developed country cities of similar size – as a result of high levels of public transport usage, strong investment in infrastructure and policies to promote alternatives to private motor vehicle use – while the extensive public transport system in New York City means that car ownership and usage levels are much lower than those in the US as a whole. The contribution of transportation to GHG emissions in Bangkok is described in Box 3.1.

Even when cars are chosen as the mode of transport, there are large variations in the GHG emissions produced by different sizes and types of vehicles. Within conventional private automobiles, there is a fourfold difference in their GHG emissions per kilometre. More efficient engines and greater use of diesel engines have the potential to reduce emissions. However, in the US, gains from engine efficiency have been offset as car weights and power have increased – meaning that overall fuel economy has hardly changed in the last 15 years.[48] Other factors that affect the contribution of urban transportation to GHG emissions include vehicle trip frequencies (starting a vehicle when it is cold uses more energy and emits more CO_2 than starting the vehicle after it has warmed up) and vehicle operating speeds (motor vehicles with internal combustion engines are most efficient at an average speed of about 72km per hour). In spite of these issues, urban design that encourages less frequent car use will generate far greater benefits than the small losses associated with engine start-up; and roadway design that encourages higher speeds is likely to cause an increase in distances travelled by cars that will be far greater than any efficiency benefits.[49]

There is a strong association between rising income and car use in developing countries, meaning that economic growth in developing countries is very likely to result in increased car use and rising traffic congestion.[50] In addition, in many developing countries, the stock of motor vehicles is old and consists largely of second-hand and less efficient vehicles imported from developed countries. At the same time, the conversion of vehicles to use different fuels has the potential to reduce GHG emissions in many cities in developing countries. In Mumbai (India), for example, it has been estimated that the conversion of more than 3000 diesel-fuelled buses to compressed natural gas would result in a reduction of 14 per cent of total transport-related emissions.[51]

Table 3.9

Ground transportation, fuel consumption and GHG emissions, selected cities

City	Gasoline consumption (million litres)	Diesel consumption (million litres)	GHG emissions (tonnes CO_2eq per capita)
Denver (US)	1234	197	6.07
Los Angeles (US)	14,751	3212	4.74
Toronto (Canada)	6691	2011	3.91
Bangkok (Thailand)	2741	2094	2.20
Geneva (Switzerland)	260	51	1.78
New York City (US)	4179	657	1.47
Cape Town (South Africa)	1249	724	1.39
Prague (Czech Republic)	357	281	1.39
London (UK)	1797	1238	1.18
Barcelona (Spain)	209	266	0.75

Source: Kennedy et al, 2009b

There is a strong association between rising income and car use in developing countries, meaning that economic growth … is very likely to result in increased car use

Box 3.1 The contribution of transportation to GHG emissions in Bangkok, Thailand

With approximately 7 million people, or more than 10 per cent of Thailand's population, Bangkok is not only the national capital, but also its focus for communications, its administrative centre and a major business hub for Southeast Asia. While the city's population has grown rapidly during the last 50 years, the population of the inner city has been declining as people have moved to suburban areas. Between 1978 and 2000, the population of the inner city declined from 3.25 million to 2.86 million, with a corresponding decrease in density from 15,270 to 11,090 people per square kilometre. Per capita emissions from Bangkok are at a similar level to many European and North American cities, with a figure of 7.1 tonnes per capita per annum.

Transportation is the single greatest source of Bangkok's GHG emissions, responsible for 23 million tonnes CO_2eq per year, or 38 per cent of the city's total. Electricity is the second largest contributor (33 per cent), followed by solid waste and wastewater (20 per cent). The contribution of this sector is growing rapidly: the number of vehicles registered in the city has soared from 600,000 in 1980 to 5.6 million in 2007, an almost tenfold increase. Indeed, since 2003, more than 500,000 additional vehicles have been registered in Bangkok each year.

Sources: Bangkok Metropolitan Administration, 2009; UN, 2010

There are currently … nearly 1.2 billion passenger vehicles worldwide. By 2050, this figure is projected to reach 2.6 billion – the majority of which will be found in developing countries.

GHG emissions from commercial and residential buildings are closely associated with emissions from electricity use, space heating and cooling

The type of fuel used for heating and cooling also determines the amount of GHGs emitted

The issue of emissions from transportation in developing countries is particularly important in countries where motor vehicle ownership is expanding rapidly. There are currently (2011) nearly 1.2 billion passenger vehicles worldwide. By 2050, this figure is projected to reach 2.6 billion – the majority of which will be found in developing countries.[52] The emissions associated with the increase in passenger vehicles can be reduced either through advances in fuel technology or by changes from one mode of transportation to another. The potential for such reductions is particularly strong in urban areas – with the advantage of relatively high densities of people, economic activities and cultural attractions. In Bogotá (Colombia), a bus rapid transit system (known as TransMilenio) – combined with car-restriction measures (including a path-breaking 'car-free' Sunday in which 120km of arterial roadways are closed to private motorized vehicles) and the development of new cycle-ways – has shown that an erosion of the relative importance of the public transport mode is not preordained.[53] Similar systems have also been proposed for several cities in Africa and Asia – for example, in Dar es Salaam.[54]

Current modes of urban transportation have many other adverse effects. According to the World Health Organization, more than 1.2 million people were killed in road traffic accidents in 2002. Projections indicate that this figure will increase by 65 per cent by 2020.[55] Reducing the reliance on private motor vehicles may help to reduce this figure. In addition, heavy reliance on personal transportation results in physical inactivity, urban air pollution, energy-related conflict and environmental degradation. Alternative modes of transport – particularly walking and cycling – can generate co-benefits, including improved human health through reducing obesity alongside reduced GHG emissions.[56] In addition, reducing the number of vehicles on the road can reduce local-source air pollution which is directly linked to mortality, cardiovascular diseases and respiratory illnesses, including asthma among young children.[57]

Perhaps the most notable omission from the above discussion is emissions from the aviation industry, which account for about 2 per cent of total anthropogenic GHG emissions.[58] These are not included within a country's national GHG inventory as a result of the lack of consensus as to where exactly these should be allocated. Should these be assigned to the country from which the aircraft takes off; the country in which the aircraft lands; the country in which the aircraft is registered; or the country of origin of the passengers? These issues are even more complex in the case of city emissions, as many of the passengers using major international airports situated in or close to major cities may be from elsewhere in the country, or may only be using these airports for transit purposes. The IPCC has estimated that aviation is responsible for around 3.5 per cent of human-induced climate change – the emissions from high-flying aircraft cause a greater amount of warming than the same volume of emissions would do at ground level – and that this is growing by approximately 2.1 per cent per year.[59]

Globally, shipping is responsible for about 10 per cent of transportation energy use;[60] but emissions from international maritime transportation are not included within national GHG inventories for similar reasons. Although international maritime transport is essential for servicing the needs of urban areas, the role of urban centres as ports and trans-shipment points means that allocating responsibility for the emissions associated with this is difficult, if not impossible.

The GHG inventories produced by London and New York offer an alternative set of figures that do take emissions from aviation into account. As a major air travel hub, London's airports handle 30 per cent of the passengers entering or departing the UK. If incorporated within the city's emissions inventory, aviation would be responsible for 34 per cent of London's emissions, and would raise total emissions from 44.3 million tonnes to 67 million tonnes for 2006.[61] In the case of New York (US), aviation would add 10.4 million tonnes per year to the city's emissions.[62] However, as is the case with industrial emissions, allocating the responsibility for all aviation-based emissions to a city's inventory is misleading – large city airports provide a service not only to individuals from elsewhere in the same country, but also from abroad.

Commercial and residential buildings

GHG emissions from commercial and residential buildings are closely associated with emissions from electricity use, space heating and cooling. When combined, the IPCC estimates global emissions from residential and commercial buildings at 10.6 billion tonnes of CO_2eq per year,[63] or 8 per cent of global GHG emissions (see Figure 1.4). Commercial and residential buildings are responsible for both direct emissions (onsite combustion of fuels), indirect emissions (from public electricity use for street lighting and other activities and district heat consumption) and emissions associated with embodied energy (e.g. in the materials used for their construction). Emissions are affected by the need for heating and cooling, and by the behaviour of building occupants.

The type of fuel used for heating and cooling also determines the amount of GHGs emitted. Although Prague in the Czech Republic uses less energy per capita for heating than New York City (US), its emissions from heating are higher due to its reliance on coal. To a lesser extent, the emissions of Cape Town (South Africa) and Geneva (Switzerland) are also slightly higher than other comparable cities due to the predominance of oil instead of natural gas for heating.[64]

Data are available for the US on the direct final consumption of fossil fuels in buildings and industry.[65] However, it is not possible to separate the consumption of fuel between residential, commercial and industrial uses. Natural gas and fuel oil are the primary sources of energy for heating these buildings, while electricity is the main source of energy for cooling. Consequently, urban areas in warmer climate zones (where cooling, rather than heating, is required) tend to have lower direct final consumption of fossil fuels, whereas the inverse is the case in cooler climate zones. However, there are also regional differences in fuel composition. The US Northeast relies more on fuel oil, which emits a greater volume of CO_2 per unit of energy, while the US north Midwest relies more on natural gas.

The average size of new single-family homes in the US has expanded during recent years. Larger houses occupy more land, require greater amounts of material for construction, and consume more energy for heating and cooling. Larger homes are typically associated with higher incomes and higher energy consumption (see Table 3.10), and are found more often in sprawling counties.[66] Overall patterns of residential density also affect GHG emissions: the most densely settled area of the US (the Northeast, with 873 persons per square kilometre) has the lowest per capita annual energy consumption (283 million kilojoules), CO_2 emissions (15.0 tonnes) and vehicle distance travelled (13,298km) in the country.[67]

In the UK, residential buildings are responsible for 26 per cent of all CO_2 emissions, commercial and public buildings for 13 per cent, and industrial buildings for 5 per cent.[68] Most energy consumption (84 per cent) in residential buildings is from the heating of space and water. As the primary fuel for this is natural gas (which has a lower carbon content than electricity), this is only responsible for 74 per cent of CO_2 emissions. In non-residential buildings, heating (37 per cent) and lighting (26 per cent) are the main sources of CO_2 emissions.

Estimates for residential energy use per unit area for the UK and the US are 228 and 138kWh per square metre per year, respectively.[69] Since the average dwelling size is much greater in the US (200 compared to 87 square metres), the US uses more energy per household. For non-residential buildings, energy use in the UK, the US and India are 262, 287 and 189kWh per square metre per year, respectively.

In China, energy consumption of buildings accounts for 27.6 per cent of national energy consumption and contributes 25 per cent of national GHG emissions. In total, the country has 40 billion square metres of built space, of which only 320 million square metres can be identified as 'energy-saving buildings'. The Energy Efficiency in Building and Construction programme aims to ensure that, by 2010, new urban buildings will reach a new design standard of reducing energy consumption by 50 per cent.[70] At a smaller scale, various initiatives are being implemented in other middle-income countries such as South Africa, including the development of low-cost, low-energy houses for the urban poor. These employ simple technologies such as north-facing orientation and roof overhangs to maintain comfortable indoor temperatures without the use of heating or cooling equipment.[71]

The growth in India's population, coupled with the rapidly increasing consumer expectations of its middle class, means that emissions from that country's building stock are becoming increasingly important. During 2005/2006, only about 1 per cent of India's urban households used electricity for cooking, 59 per cent used natural gas or liquefied petroleum gas, 8 per cent used kerosene, 4 per cent used coal or lignite, and the rest, about 27 per cent, used firewood, charcoal, biomass or other energy sources.[72] Approximately one third of India's energy is supplied by large hydropower plants with limited GHG emissions. In the Indian residential sector, fans account for 34 per cent of total electricity consumption, lighting for 28 per cent and refrigeration for 13 per cent.[73] Of particular relevance for buildings in India is the large amount of electricity used by heating, ventilation and air-conditioning systems. In buildings without this facility, lighting is the main component of energy consumption, whereas in buildings with heating, ventilation and air-conditioning systems, these account for 40 to 50 per cent of consumption. However, there are large disparities between income groups: low-income groups in urban areas rely heavily on kerosene and liquefied petroleum gas for energy alongside electricity, and a significant proportion still use firewood or other biomass fuels. India's commercial sector uses electricity primarily for lighting (60 per cent of consumption) and heating, ventilation and air-conditioning systems (32 per cent).[74]

Household income level (US$)	Household area (m^2)	Energy consumption of household (million kilojoules)
$15,000–$19,999	139.4	85
$30,000–$39,999	157.9	92
$75,000–$99,999	250.8	119
$100,000 or more	315.9	143

Source: based on Markham, 2009, p12

Table 3.10

Energy consumption by income level and dwelling size in the US (2008)

Industry[75]

Globally, 19 per cent of GHG emissions are associated with industrial activities (see Figure 1.4). Although most cities in North America and Europe emerged and developed as a result of industrial activities, and still require industries to provide jobs and revenue, these same activities generate pollution. However, during recent decades the global pattern of industrial activities has shifted, in part due to transnational corporations seeking lower wages and higher profitability, and in part due to the increasing success of companies and corporations from China, India, Brazil and elsewhere in competing on the world market. Differences in environmental legislation have also transformed the geography of industrial location. It has been noted that 'when [cities] are able, they will get rid of polluting industries, pushing them away from city centers to suburbs or to other cities'.[76]

Many industrial activities are energy intensive in their operation. These include the manufacture of iron and steel, non-ferrous metals, chemicals and fertilizer, petroleum refining, cement, and pulp and paper. There are differences in industrial emissions according to location and according to the size of the industry. In developing countries, some facilities are new and incorporate the latest technology. Yet, small- and medium-sized enterprises may not have the economic or technical capacity to install the latest energy-saving equipment. The industrial processes mentioned above are responsible for direct GHG emissions. In Los Angeles (US), Prague (Czech Republic), and Toronto (Canada) these add 0.22, 0.43 and 0.57 tonnes of CO_2eq per capita per annum, respectively.[77]

Larger houses … consume more energy for heating and cooling

Differences in environmental legislation have also transformed the geography of industrial location

Although waste generation is linked to population, affluence and urbanization, emissions from waste may be lower in more affluent cities, as urban areas have the potential to greatly reduce – or even eliminate – emissions from waste

GHG emissions from waste are relatively low in many urban areas in developed countries

Global urban trends towards suburbanization mean that cities are sprawling and encroaching on land that may previously have been covered with vegetation – thereby reducing its potential to absorb CO_2

A study of 15 South African cities shows that, on average, manufacturing caused half of all GHG emissions. However, in towns characterized as 'heavy industrial', manufacturing's share rose to 89 per cent, and residential share declined to 4 per cent. This accounts for the extraordinarily high per capita emission in some of these industrial towns. Saldanha Bay (a large port and industrial centre in Western Cape Province) and uMhlatuze (a port in KwaZulu-Natal that includes two aluminium smelters and a fertilizer plant) have per capita emissions of 50 and 47 tonnes of CO_2 emissions per annum, respectively (see Table 3.13). However, 93 per cent of emissions from Saldanha Bay and 95 per cent of emissions from uMhlatuze are generated by industry and commerce, with households being responsible for only 1.9 per cent and 1.5 per cent of emissions, respectively.[78]

Similar patterns exist in China, where the ratio of urban to rural per capita commercial energy usage is 6.8.[79] This reflects a situation in which the industrial sector has tended to dominate urban CO_2 emissions, although this has been declining in some cases. Between 1985 and 2006, the share of the industrial sector in total CO_2 emissions from Beijing declined from 65 to 43 per cent; and in Shanghai from 75 to 64 per cent. However, rather than representing an absolute decline, this reflects the growing significance of the transportation sector. CO_2 emissions from transportation rose sevenfold in Beijing and eightfold in Shanghai over the same time period. Another set of estimates suggests that between 1990 and 2005, 90 per cent of Shanghai's energy was consumed by the industrial sector and only 10 per cent by 'family life', although these figures appear to exclude energy consumption by transportation.[80]

Waste

Emissions from waste represent about 3 per cent of total emissions (see Figure 1.4). Despite being only a small contributor to global emissions, rates of waste generation have been increasing during recent years, particularly in developing countries that have been experiencing increasing affluence. Although waste generation is linked to population, affluence and urbanization,[81] emissions from waste may be lower in more affluent cities, as urban areas have the potential to greatly reduce – or even eliminate – emissions from waste. The concentration of people and activities in urban areas means that waste can be collected efficiently, and methane emissions from landfills can be captured and flared or used to generate electricity. Although many developing countries lack the technology for methane recuperation, landfill gas capture projects funded through the Clean Development Mechanism (CDM),[82] which are increasingly being implemented even in the least developed countries (e.g. at the Mtoni dumpsite in Dar es Salaam, Tanzania), offer numerous potentials.

As a result of some of the above-mentioned initiatives, GHG emissions from waste are relatively low in many urban areas in developed countries. Per capita emissions from waste in Barcelona (Spain), Geneva (Switzerland), London (UK), Los Angeles (US), New York (US), Prague (Czech Republic) and Toronto (Canada) are all less than 0.5 tonnes CO_2eq per capita per annum; while those from Bangkok (Thailand) and Cape Town (South Africa) are 1.2 and 1.8 tonnes CO_2eq per capita per annum, respectively.[83] Indeed, New York has negative net emissions as a result of the capture of methane from managed landfills, while in São Paulo (Brazil), Barcelona (Spain) and Rio de Janeiro (Brazil) solid waste is responsible for 23.6, 24 and 36.5 per cent of urban emissions, respectively.[84] These variations are likely to be due not only to different patterns of consumption and waste generation, but also to differences in the management of waste and differences in accounting mechanisms – variations that are almost impossible to assess in the absence of a standardized urban framework for conducting emissions inventories.

Agriculture, land-use change and forestry

At a global level, 14 per cent of GHG emissions can be allocated to activities related to agriculture and 17 per cent to forestry (see Figure 1.4). Although these are often thought of as being rural activities, urban agriculture can be an important component of local economies and food supply systems, and many urban areas do include parks and forests. The broader ecological impacts of cities have been increasingly studied during recent years,[85] based on the recognition that the expansion of built-up areas transforms rural landscapes; that city-based enterprises, households and institutions place demands on forests, farmlands and watersheds outside urban boundaries; and that solid, liquid and airborne wastes are transferred out of the city to the surrounding region or further afield.[86]

Specifically in relation to climate change, urban areas can shape emissions from agriculture, land-use change and forestry in two major ways. First, the process of urbanization can involve direct changes in land use, as formerly agricultural land becomes incorporated within built-up areas. The world's urban population multiplied tenfold during the 20th century, meaning that more land was covered by urban development. Equally, global urban trends towards suburbanization mean that cities are sprawling and encroaching on land that may previously have been covered with vegetation – thereby reducing its potential to absorb CO_2. Second, the consumption patterns of increasingly wealthy urban residents can shape the type of agricultural activities that is taking place. For example, the growing consumption of meat products is associated with emissions of methane from livestock rearing.

THE SCALE OF URBAN EMISSIONS

It is impossible to make definitive statements about the scale of urban emissions. There is no globally accepted standard for assessing the scope of urban GHG emissions – and even if there was, the vast majority of the world's urban centres have not conducted an inventory of this type. Current administrative differences in the extent, frequency and thoroughness of inventories contribute to substantial variations in the scope, accuracy and comparability of these. Perhaps the two most substantial differences between inventories are related to boundary issues and scope issues. These issues are discussed in greater detail in the next two sections.[87] This section presents the results from a range of previously conducted GHG inventories, assesses their findings, and identifies common themes across developed and developing countries.

Global patterns of emissions

The economic activities, behavioural patterns and GHG emissions from urban areas are shaped by the overall economic, political and social circumstances of the countries in which they are located. At a global level, there are striking differences in GHG emissions between regions and countries. The 18 per cent of the world's population living in developed countries account for 47 per cent of global CO_2 emissions, while the 82 per cent of the world's population living in developing countries account for the remaining 53 per cent. The US and Canada alone account for 19.4 per cent of global GHG emissions, while South Asia accounts for 13.1 per cent and Africa just 7.8 per cent.[88] Even greater differences can be seen if individual countries are compared: per capita CO_2eq emissions vary from less than 1 tonne per year for Bangladesh and Burkina Faso to more than 20 tonnes for Canada, the US and Australia.[89] These variations among countries are shown in greater detail in Figure 3.3.

In addition, global growth in GHG emissions has not been distributed evenly between countries. Between 1980

Per capita CO_2eq emissions vary from less than 1 tonne per year for Bangladesh and Burkina Faso to more than 20 tonnes for Canada, the US and Australia

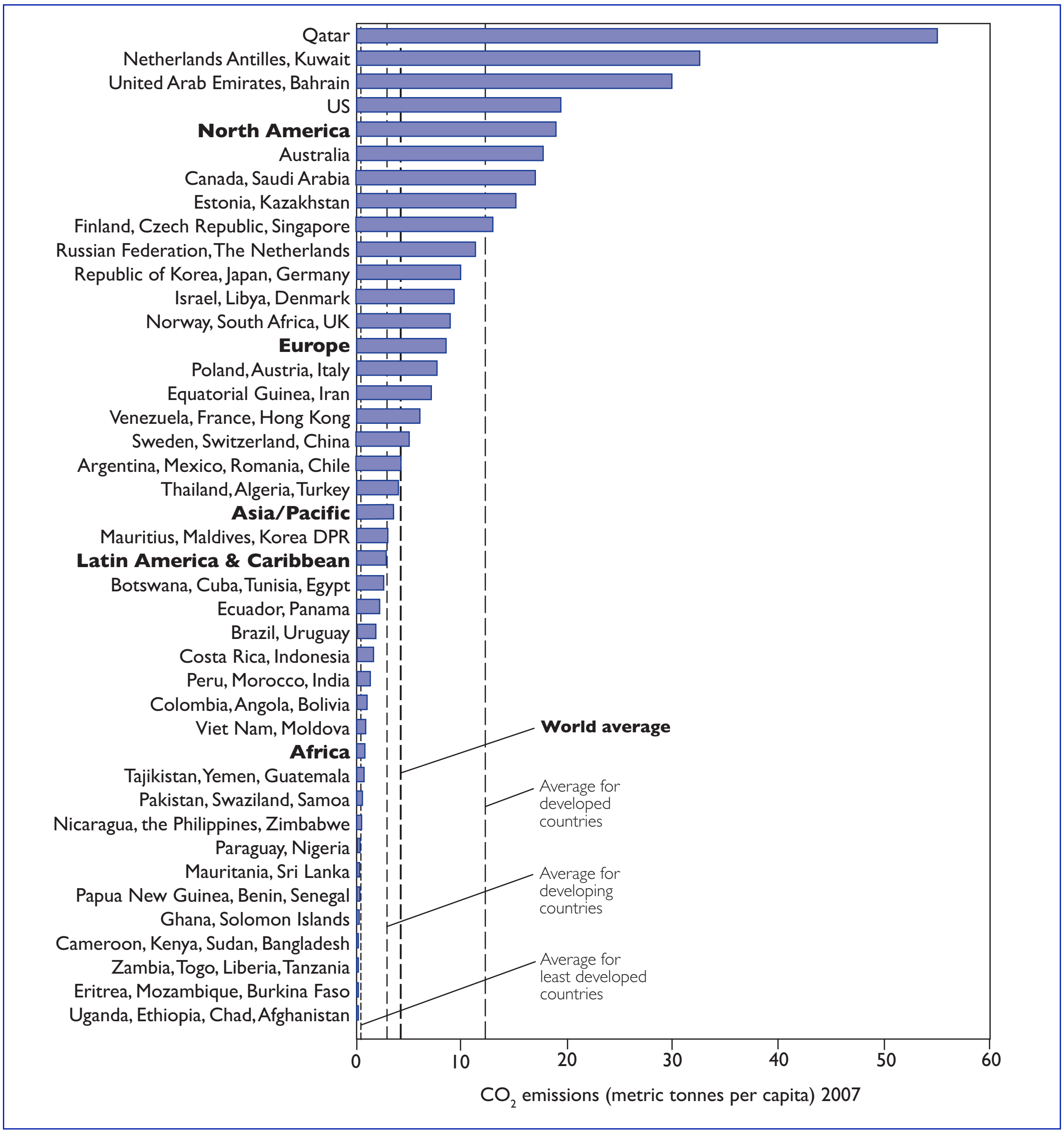


Figure 3.3

CO_2 emissions per capita in selected countries and world regions (2007)

Sources: based on http://mdgs.un.org/unsd/mdg (last accessed 21 October 2010); and UN, 2010

Table 3.11

Comparisons of city and national GHG emissions, selected cities

City	GHG emissions per capita (tonnes of CO_2eq) (year of study in brackets)	National emissions per capita (tonnes of CO_2eq) (year of study in brackets)
Washington, DC (US)	19.7 (2005)	23.9 (2004)
Glasgow (UK)	8.4 (2004)	11.2 (2004)
Toronto (Canada)	8.2 (2001)	23.7 (2004)
Shanghai (China)	8.1 (1998)	3.4 (1994)
New York City (US)	7.1 (2005)	23.9 (2004)
Beijing (China)	6.9 (1998)	3.4 (1994)
London (UK)	6.2 (2006)	11.2 (2004)
Tokyo (Japan)	4.8 (1998)	10.6 (2004)
Seoul (Republic of Korea)	3.8 (1998)	6.7 (1990)
Barcelona (Spain)	3.4 (1996)	10.0 (2004)
Rio de Janeiro (Brazil)	2.3 (1998)	8.2 (1994)
São Paulo (Brazil)	1.5 (2003)	8.2 (1994)

Source: Dodman, 2009

and 2005, CO_2 emissions increased by more than 5 per cent per year in the Republic of Korea, China and Thailand. Yet, over the same period, emissions from Chad, the Democratic Republic of Congo, Liberia and Zambia declined by an average of more than 1 per cent per year.[90] As these figures suggest, many of the countries with currently very low emissions are not experiencing rapid increases in emissions. However, if rapid economic growth takes place, this situation may change. Various attempts have been made to compile GHG inventory figures for cities around the world. Data from two recent studies are presented in Tables 3.11 and 3.12. The information in both tables is intended to be illustrative of well-documented cases from a range of countries. One of the most striking features of these emissions inventories is that average per capita emissions for many large cities are substantially lower than for the country in which they are located (see Table 3.11; see also Table 3.5). For example, per capita emissions in New York City are 7.1 tonnes annually, compared to 23.9 tonnes for the US; those for London are 6.2 tonnes compared to 11.2 for the UK; and those for São Paulo are 1.5 tonnes compared to 8.2 for Brazil. Although this is not a complete global analysis, it nonetheless suggests that – for a given level of economic development – urban areas offer the opportunity to support lifestyles that generate smaller quantities of GHG emissions.

A wide range of cities in the US have produced GHG inventories

Table 3.12

GHG emissions inventories, selected cities

City	Emissions per capita (tonnes of CO_2eq per year)		
	Emissions within city	Direct emissions	Life-cycle emissions[a]
Denver (US)	n/d	21.5	24.3
Los Angeles (US)	n/d	13.0	15.5
Cape Town (South Africa)	n/d	11.6	n/d
Toronto (Canada)	8.2	11.6	14.4
Bangkok (Thailand)	4.8	10.7	n/d
New York City (US)	n/d	10.5	12.2
London (UK)	n/d	9.6	10.5
Prague (Czech Republic)	4.3	9.4	10.1
Geneva (Switzerland)	7.4	7.8	8.7
Barcelona (Spain)	2.4	4.2	4.6

Notes: n/d = not determined.

a Life-cycle emissions are associated with the transportation of goods and people outside city boundaries, and with the production of key urban materials, including food, water and materials for shelter, but that may not be directly emitted from within the cities' geographical boundaries.

Source: Kennedy et al, 2009b

Urban emissions in developed countries

Many urban areas in developed countries have their origins (or their change in scale) in the industrial revolution and the rapid expansion of manufacturing during the 18th and 19th centuries. The industrial hubs of northern England, the Rhine-Ruhr Valley in Germany and the north-eastern seaboard of the US all developed in close proximity to heavy raw materials such as coal and iron ore. However, since the middle of the 20th century, the economies of these regions have shifted away from secondary industry into tertiary and quaternary industries. As will be seen from the examples discussed below, this means that their emissions from the manufacture of products are relatively low. At the same time, these urban areas have become centres of wealth and consumption. The lifestyles of their residents – particularly related to consumption and travel – generate a large carbon footprint; yet this is seldom accounted for in emissions inventories.

■ Urban emissions in North America

Toronto, Canada, was one of the earliest cities to recognize the need to reduce CO_2 emissions. In January 1990, the city council declared an official target of reducing the city's CO_2 emissions to 20 per cent below the 1988 level by 2005.[91] A more recent survey estimated per capita emissions of 8.2 tonnes in 2001, compared to a Canadian average of 23.7 tonnes (in 2004).[92]

A wide range of cities in the US have produced GHG inventories, although only a few of these are discussed here to highlight particular issues. The overall per capita GHG emissions for Washington, DC, are relatively high compared with the other North American cities – with a value of 19.7 tonnes CO_2eq per capita each year, compared to a US average of 23.9 tonnes. Although Washington, DC, is a densely populated urban centre, with very little in the way of industrial activities, it also has a relatively small population (572,059 in 2000) in relation to the large number of offices for government and related functions, and large sections are very wealthy. In this regard, it would have been more appropriate (if data had been available) for comparative purposes to compare with the emissions from the entire Washington, DC, metropolitan area.[93]

New York City's total GHG emissions were estimated to be 61.5 million metric tonnes of CO_2eq, which equates to per capita emissions of 7.1 tonnes in 2007 (see Figure 3.4). A detailed description of New York City's contribution to GHG emissions is presented in Box 3.2. New York City's emissions are relatively low for a wealthy city in a developed country as a result of small dwelling sizes, high population density, an extensive public transport system, and a large number of older buildings that emphasize natural daylighting and ventilation. Electricity accounts for about 38 per cent of total CO_2eq emissions. The New York City electricity fuel mix is dominated by natural gas, but also includes coal, oil, nuclear and hydropower. Natural gas is also the dominant heating fuel and direct consumption of natural gas accounts for 24 per cent of emissions.[94]

In the US as a whole, transportation is the largest end-use sector, accounting for 33.1 per cent of total emissions in

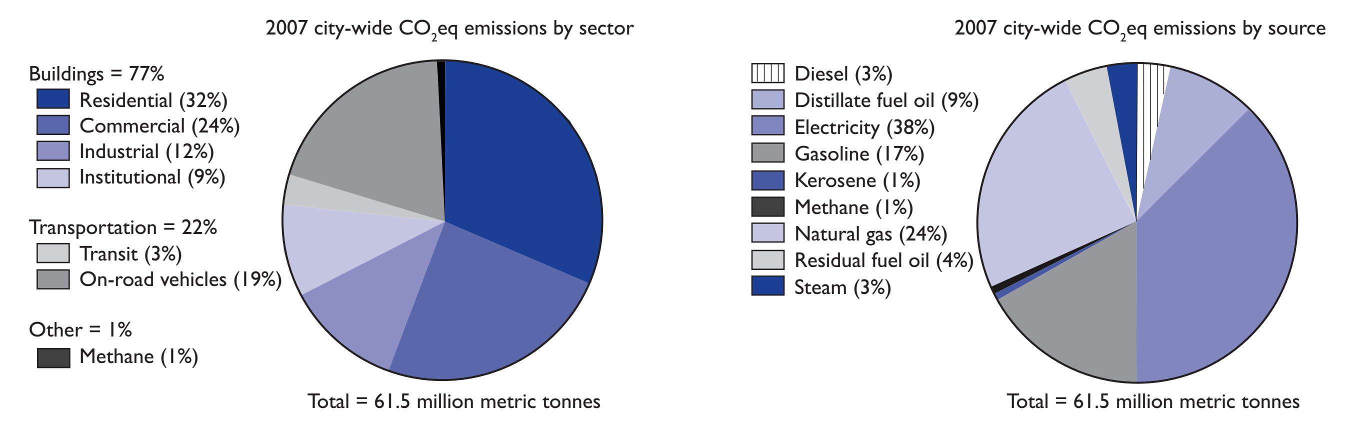


Figure 3.4

GHG emissions inventory, New York City, US

Source: City of New York, 2009

the country.[95] Emissions from transportation in New York City were 13 million metric tonnes of CO_2eq during the fiscal year of 2007, or 22 per cent of the city's total CO_2eq emissions, which was well below the average for the US.[96] Although the city's official inventory did not include GHG emissions from aviation and shipping, emissions from aviation have been estimated at 10.4 million metric tonnes, while emissions from transportation of freight by water have been estimated at 6.2 million metric tonnes.[97] Residential and commercial buildings each account for a larger share of emissions than transportation, and, overall, buildings account for 77 per cent of GHG emissions (although this does include industry) (see Figure 3.4). The share of building-sector emissions in New York City is larger than in the US as a whole both because of reduced transportation-sector emissions resulting from an effective public transit network and because of the city's large and energy-intensive commercial sector. Since buildings account for the majority of emissions, this sector is likely to be the key focal point for emissions reduction policies in New York City.

As noted in Box 3.2, New York City has set a target of a 30 per cent reduction in government operations emissions by 2030.[98] The GHGs emitted as a result of government operations were 4.3 million metric tonnes CO_2eq in 2007, representing approximately 7 per cent of the city-wide total. Similar to the city-wide results, buildings account for the vast majority of city government emissions (63 per cent). The city's municipal vehicle fleet accounts for 8 per cent of the total.[99]

New York City's 2007 city-wide inventory showed that CO_2eq emissions decreased by 2.5 per cent between 2005 and 2007. Although energy consumption increased between these two years, the carbon intensity of the electricity supply decreased when two new efficient power plants were introduced in 2006, displacing electricity generated from less efficient plants with higher CO_2eq coefficients. This change alone reduced emissions by approximately 3.2 million metric tonnes (5 per cent reduction). Milder winter and summer weather conditions in 2007 compared with 2005 also contributed to the reduction. 'Heating degree days' and 'cooling degree days', which reflect the demand for energy needed to heat or cool a home or business, decreased by 0.6 and 17.7 per cent, respectively, from 2005 to 2007.[100]

A very different picture emerges from the emissions inventory of Aspen, Colorado (US).[101] The inventory gives an overall figure of 50 tonnes CO_2eq per capita per annum, but also shows how various methods for calculation can lead to different results. Aspen is a major tourist destination, and the figure includes a calculation to allocate emissions to this group of temporary residents. If this is removed, then per capita emissions for the *resident* population rise to 102.5 tonnes CO_2eq. The overall figure includes air transportation – and if this is removed, as well as tourist driving and commuting to locations outside Aspen, then the equivalent figure falls to 40.3 tonnes CO_2eq. Whichever figure is used is considerably higher than the US national average, and this indicates the high emissions from relatively small towns in predominantly rural areas. Aspen is a very wealthy town with a high reliance on the tourism industry (which may be seen as energy intensive in its own right), and requires substantial heating because of its mountainous location.

A report by the Brookings Institution examines the per capita carbon footprints of individuals (rather than comprehensive GHG inventories) from the 100 largest metropolitan areas in the US from 2000 to 2005.[102] The

New York City's 2007 city-wide inventory showed that CO_2eq emissions decreased by 2.5 per cent between 2005 and 2007

Box 3.2 Contribution to GHG emissions, New York City, US

New York is the largest city in the US and a global centre of commerce and culture. The city itself has a population of 8.25 million and forms the core of the New York Metropolitan Area, with a population of 18.8 million. The city produces approximately 8 per cent of total US gross domestic product (GDP) and is a leading financial centre. In general, the city's total emissions are high, but per capita emissions are low in comparison to other urban areas in the US.

The city's greenhouse gas (GHG) emissions are dominated by energy-related activities: more than two-thirds of the city's emissions are associated with electricity and fuel consumption in residential, commercial and institutional buildings. A further 22 per cent is associated with transportation – this is low by US standards, as the city has the highest rate of commuting by public transport in the country. Three-quarters of the methane produced at landfills and wastewater treatment plants is captured, so this represents a very small source of emissions.

The City of New York has been completing GHG emissions inventories since 2007 and has passed a law requiring annual updates to this. This is associated with PlaNYC: the mayor's comprehensive sustainability plan for the city's future, which has set goals including reducing GHG emissions by 30 per cent by 2030. Measures to achieve this are associated with upgrading the local power supply (by replacing inefficient power plants with more advanced technologies), reducing energy consumption (by imposing more aggressive energy codes for new buildings and promoting energy efficiency in existing buildings) and reducing transport-related emissions (through the expanded use of public transportation).

Sources: Parshall et al, 2009, 2010

report concludes that despite housing two-thirds of the US population and three-quarters of its economic activity, these metropolitan areas emitted just 56 per cent of the country's GHG emissions from highway transportation and residential buildings. However, the footprints that were assessed were only partial, and included only highway transportation and energy consumption in residential buildings – and not emissions from commercial buildings, industry or non-highway transportation. Even within these parameters, there were large differences between metropolitan areas: from 1.36 tonnes per capita in Honolulu (Hawaii, US) to 3.46 tonnes per capita in Lexington (Kentucky, US).

In comparison to North American cities, the contribution of urban areas in Europe to climate change is relatively low

Urban emissions in Europe

In comparison to North American cities, the contribution of urban areas in Europe to climate change is relatively low. This is as a result of several factors. European urban areas tend to be more compact. They tend to have lower car ownership and car usage rates, smaller, more fuel-efficient cars, reducing emissions from private transportation. They tend to have more effective public transportation networks, which are deemed socially acceptable to a broader range of individuals. Furthermore, urban areas in Europe have higher levels of densification and lower levels of sprawling in relation to North American cities.

The overall CO_2 emissions of London in 2006 were 44.3 million tonnes – representing 8 per cent of the UK's total emissions, and a slight decline from the 45.1 million tonnes produced in 1990 despite a rise in population of 0.7 million people during the same time period.[103] This reduction can be attributed to the halving of industrial emissions, as industrial activity declined or has relocated to other parts of the UK or overseas. The per capita emissions from London are the lowest of any region in the UK, and at 6.2 tonnes per capita, in 2006, were just over half of the national average of 11.2 tonnes per capita (see Table 3.11). Per capita emissions from Glasgow at 8.4 tonnes per capita in 2004 are higher than those for London; but this may also reflect the fact that the analysis covered the entire area of Glasgow and the Clyde Valley, an area comprised of eight local authorities and covering an area of 3405 square kilometres. This area also emits a higher than average quantity of agricultural emissions due to a proportionally larger dairy farming sector in the area.

Barcelona, the second largest city in Spain, had a population of 1.6 million people within its administrative unit in 1996. Over the period of 1987 to 1996, the total emissions for the city grew from 4.4 million tonnes to 5.1 million tonnes. There was, however, a decline from 5.3 million tonnes to 4.9 million tonnes between 1992 and 1995. Part of this decline can be attributed to a decline in population. Indeed, between 1987 and 1995, the population of Barcelona shrank from 1.7 million to 1.5 million. Barcelona's relatively low level of per capita emissions can be attributed to several factors. These include: the city's economy is primarily service based rather than manufacturing based; 90 per cent of the city's electricity is generated by nuclear and hydro energy; the city's mild climate and the rarity of household air-conditioning systems; and the compact urban structure, in which many residents live in apartments rather than individual houses.[104]

Given the reduced importance of manufacturing in some cities, some inventories have been produced that only take into account emissions associated with electricity, transportation and waste generation. In Oeiras municipality (part of the metropolitan area of Lisbon, Portugal, with a population of 160,000), electricity accounted for 75 per cent of municipal emissions in 2003. Other sources of emissions were gaseous fuel consumption (11 per cent), waste in sanitary landfills (8 per cent), liquid fuels consumption (5 per cent) and wastewater treatment (1 per cent). The total municipal emissions in 2003 were 525,550 tonnes – or 3.3 tonnes CO_2eq per capita.[105] Liquid fuels serve as a proxy for transportation. However, this only provides information on the amount of fuel purchased, and not on the vehicle kilometres driven within the municipality. In addition, it fails to resolve important issues related to the allocation of emissions from motor vehicles – whether these should fall in the location of residence of the driver, the origin or destination of any given journey, or some combination of the above.

Emissions inventories for Geneva, Switzerland, show annual within-city emissions of 7.4 tonnes CO_2eq per capita, and for Prague, Czech Republic, show annual within-city emissions of 4.3 tonnes CO_2eq per capita. If 'life-cycle' emissions are taken into account, these figures rise to 8.7 and 10.1 tonnes CO_2eq per capita, respectively (see Table 3.12).

Very few detailed emissions inventories have been produced by cities in developing countries

Urban emissions in developing countries

Very few detailed emissions inventories have been produced by cities in developing countries. Cities in these countries are frequently economic centres that contribute significantly to the gross national product (GNP), and act as economic, political, social and cultural centres. Consequently, these cities are centres of consumption and wealth, with likely consequences including higher per capita GHG emissions than surrounding areas.

As manufacturing has declined in importance in developed countries, it has expanded rapidly in some developing countries. Countries such as Brazil, China, India and South Africa – encouraged by economic and geopolitical changes – are now centres for global manufacturing. The relatively cheap and plentiful supply of labour, and the increased ease of transporting raw materials and finished products, means that these countries can compete effectively on the world market. Yet, this competition is not without costs, some of which are associated with local environmental degradation and others with the emission of GHGs. Current global protocols for measuring emissions, and setting targets for their reduction, solely address the location of production of these GHGs, which means that some developing countries with prospering manufacturing industries appear to be major emitters.

China has recently overtaken the US as the world's leading total emitter of GHGs, although its per capita emissions are significantly lower

Some developing countries play an increasingly important role in contributing to global GHG emissions. China has recently overtaken the US as the world's leading total emitter of GHGs, although its per capita emissions are

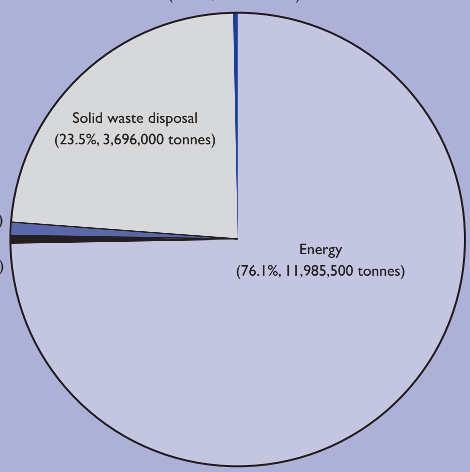
Box 3.3 Contribution to GHG emissions, São Paulo, Brazil

The São Paulo Metropolitan Region has a population of 18 million and is the largest urban area in Brazil. The city is a major driving force for the national economy, with a gross domestic product (GDP) of US$83 billion in 2003. The service industry is the main driver, accounting for 62.5 per cent of GDP. This is followed by the industrial sector, which accounts for 20.6 per cent.

A comprehensive greenhouse gas (GHG) emissions inventory was conducted in 2005. It shows that energy use accounts for more than three-quarters of the city's emissions (see figure below). Approximately two-thirds of this was associated with diesel and gasoline, and 11 per cent with electricity generation. However, the contribution of urban transportation to GHG emissions is still relatively low as a result of the mandatory blend of ethanol (23 per cent) and gasoline (77 per cent) used in most of the private fleet. Similarly, the contribution of the electricity generation sector is low as the city relies heavily on hydroelectric generation. Solid waste disposal accounted for almost one quarter of the city's emissions, or 3.7 million tonnes of CO_2eq. However, Clean Development Mechanism (CDM) projects at the Bandeirantes and São João landfills will prevent the generation of 11 million tonnes of CO_2eq by 2012 – almost removing the contribution of solid waste to the city's emissions.

Per capita emissions from the city are low, at about 1.5 tonnes CO_2eq per year (in 2003), compared to a national average for Brazil of 8.2 tonnes (1994 figure). Despite this, the growing importance of reducing global GHG emissions means that cities in middle-income countries will increasingly need to identify their emissions reduction potential and act on this.

It is important to note that although the city of São Paulo accounts for 6.8 per cent of the population of Brazil, its GHG emissions are relatively small. This is because Brazil is a large emitter of GHGs from agriculture, land-use change and forestry. In the case of deforestation, due to high rates, emissions account for 63.1 per cent of total national emissions of CO_2 and methane. The agriculture sector as a whole is responsible for 16.5 per cent of the same gases, mainly because of the size of the national herd. In the case of the extremely urbanized city of São Paulo, these emissions are insignificant.



Sources: Dubeux and La Rovere, 2010; La Rovere et al, 2005; Ministério da Ciência e Tecnologia, 2004

significantly lower.[106] Brazil, China, India and South Africa together form the 'BASIC' group of countries that – although not part of the legally binding framework to reduce emissions – recognize that their substantial emissions compel them to take a more progressive role in international climate negotiations. Specifically, these countries are at the forefront of the development of 'nationally appropriate mitigation actions'[107] and the reduction in carbon intensity of their industries, rather than absolute reductions in emissions.

Box 3.3 provides an overview of the GHG emissions from São Paulo, Brazil. As indicated, total annual emissions from São Paulo are 15.7 million tonnes, or 1.5 tonnes per capita. However, there is the potential for the transportation and solid waste sectors in the city to engage in GHG mitigation activities – for example, through CDM projects such as the landfill gas to energy project at Bandeirantes.

GHG emissions have also been calculated for Mexico City, although the figures generated vary widely: from a total of 34.9 million tonnes CO_2eq in 1996 to 60.0 million tonnes in 2000, and 62.6 million tonnes in 2004. This variation is a result of the scarcity and inconsistency of official inventories, and methodological issues related to the inclusion and exclusion of emissions from solid waste and aviation. However, even at the higher level this equates to per capita emissions of 3.6 tonnes per year, lower than the national figure of 4.6 tonnes.[108] Box 3.4 provides further insights on GHG emissions for Mexico City.

In South Africa, CO_2 emissions have been calculated from six large metropolitan areas ('metros'), four industrial towns/cities and five non-industrial towns/cities (see Table 3.13). The average annual per capita emissions from all these urban areas is 8.1 tonnes of CO_2. This is slightly lower than the national average of 8.9 tonnes, but considerably higher than the African average of 1.1 tonnes. When broken down according to type of town, 'non-industrial towns and cities' have average per capita emissions of 3.4 tonnes; 'metros', 6.5 tonnes; and 'industrial towns and cities', 26.3 tonnes. The averages for individual urban areas range from 1.7 tonnes for King Sabata to a massive 49.5 tonnes for Saldanha Bay. The main sources of these emissions also vary substantially. In industrial towns, manufacturing accounts for as much as 89 per cent of the emissions, while in non-industrial towns, this figure was only 36 per cent. This is reflected in the CO_2 emissions per economic unit of value added, which shows that this is much higher in industrial centres than in service-oriented cities. Thus:

Brazil, China, India and South Africa ... are at the forefront of the development of 'nationally appropriate mitigation actions' and the reduction in carbon intensity of their industries, rather than absolute reductions in emissions

Box 3.4 GHG emissions and climate change in Mexico City

Mexico City has one of the highest levels of air pollution in the world. With an estimated population of 20.1 million people, 3.75 million cars and 35,000 industries, the Mexico City Metropolitan area is a major emitter of greenhouse gases (GHGs). In 2007, its emission was estimated at 60 million tonnes of CO_2eq, accounting for 9.1 per cent of national emissions. Of these, 37 million metric tonnes of CO_2eq were produced within Mexico City, with transportation, industry, housing and solid waste management serving as the major contributors (43, 22, 13 and 11 per cent, respectively). About 88 per cent of all GHG emissions in Mexico City are attributed to energy consumption in the form of fossil fuels and electricity used in transportation, industry, trade, housing or services.

The Mexico City government recognizes that climate change is now the most serious threat to the ecosystems of the city, with unquestionable socio-economic consequences for the population. Consequently, the city has developed the Mexico City Climate Action Programme 2008–2012, with a total of 26 GHG mitigation actions. If implemented, they will reduce the CO_2eq emissions by 4.4 million tonnes a year, which represents 12 per cent of the annual GHG emissions in Mexico City.

Sources: Delgado, 2008; Casaubon et al, 2008

Box 3.5 Contribution to GHG emissions, Cape Town, South Africa

With a population of about 3.2 million people, the City of Cape Town accounts for 5 per cent of South Africa's total energy consumption and 5.2 per cent of the national electricity consumption. Greenhouse gas (GHG) emission from fuel types used in the city has been significant, with electricity accounting for 69 per cent; petrol, 17 per cent; and diesel, 9 per cent. Other fuels (paraffin, liquid petroleum gas, coal, heavy furnace oil and wood) account for the rest.

The city's energy and climate strategy identifies industry, transport and residential as the major sectors contributing to GHG emissions both within the City of Cape Town and in the entire Western Cape region. As a result, the City of Cape Town has an average annual emission of 6.4 tonnes of CO_2 per person (compared to Western Europe at 4.5 tonnes, and the rest of Africa at 0.6 tonnes). The emissions cause visible pollution ('brown haze'). In 2003, air quality monitoring stations recorded 162 days of poor air quality. An earlier *Cape Town Brown Haze Study*, conducted in 1997, attributed 65 per cent of the brown haze to vehicular emission, of which 49 per cent is caused by diesel vehicles and 16 per cent by petrol vehicles.

Sources: City of Cape Town, 2006, 2007

Assessments and comparisons done using the CO_2/unit of economic value created have to be viewed with caution. Because of economic linkage between cities, economic value created with relatively low CO_2 emissions in one city might depend on the economic value created with much higher emissions in another. For example, while the City of Johannesburg measures 9.6 tonnes CO_2/R100,000 [South African rand] compared with 133.6 tonnes CO_2/R100,000 for Sedibeng, the City of Johannesburg derives components of its economic value creation through provision of low-energy-intensity services to high-energy-intensity industries in Sedibeng … the cities cannot be seen in isolation.[109]

Further assessment of Cape Town's GHG emissions shows that electricity use is responsible for 69 per cent of emissions (see Box 3.5). This high level of emissions is related to the fact that 95 per cent of South Africa's electricity generation is coal fired, with high levels of emissions for given quantities of energy. By sector, transport accounts for 54 per cent of energy use, followed by commerce and indus-

Table 3.13

CO_2 emissions from South African urban areas (2004)

Town/city	Population	Total CO_2 emissions (tonnes)	CO_2 per capita (tonnes)	CO_2 per 100,000 South African rand value added*
City of Cape Town	3,069,404	19,736,885	6.4	13.7
City of Johannesburg	3,585,545	19,944,863	5.6	9.6
City of Tshwane	1,678,806	13,537,109	8.1	12.7
Ekurhuleni	2,761,253	22,917,257	8.3	24.9
eThekwini	3,269,641	18,405,182	5.6	15.6
Nelson Mandela	1,013,883	4,754,204	4.7	13.8
Total for 'metros'	**15,378,532**	**99,295,500**	**6.5**	**14.1**
uMsunduzi	562,373	3,543,806	6.3	N/A
Saldanha Bay	79,315	3,923,771	49.5	30.2
Sedibeng	883,772	25,257,942	28.6	133.6
uMhlatuze	360,002	16,816,074	46.7	140.1
Total for 'industrial towns/cities'	**1,885,462**	**49,541,593**	**26.3**	**123.1**
Buffalo City	702,671	2,449,144	3.5	106.9
King Sabata	421,233	713,526	1.7	N/A
Mangaung	662,063	2,495,297	3.8	16.7
Potchefstroom	129,075	634,580	4.9	15.4
Sol Plaatje	196,846	882,234	4.5	13.9
Total for 'non-industrial towns/cities'	**2,111,888**	**7,174,781**	**3.4**	**15.7**
Total for towns/cities reviewed	**19,375,882**	**156,011,874**	**8.1**	**13.0**
Total for South Africa	**46,586,607**	**391,327,499**	**8.4**	**N/A**

Notes: * In 2004, US$1 was worth an average of 6.5 South African rand. N/A = not available.

Source: Sustainable Energy Africa, 2006 try (29 per cent), residential (15 per cent) and local authority (2 per cent).[110]

It needs to be emphasized that the responsibility for these emissions is not distributed evenly throughout the urban population. While more affluent urban residents consume resources – including fuel for heating or cooling, petrol or diesel for transportation, food items and consumer goods with high levels of 'embedded carbon' – in similar quantities to urban residents in developed countries, poorer urban residents use very little of these resources. Although this is an issue in all urban centres, it is particularly evident in highly unequal societies.

A recent study in India showed that the average GHG emissions of the wealthiest 1 per cent of the Indian population are 4.52 tonnes CO_2eq per annum, or more than four times as much as the 1.11 tonnes CO_2eq per annum generated by the poorest 38 per cent of the population.[111] A significant proportion of urban residents in low-income countries have very low levels of GHG emissions because of their limited use of fossil fuels, limited use of electricity, and limited consumption of goods and services that require GHG emissions for their production and transportation. Indeed, many low-income urban dwellers whose livelihoods are based on reclaiming, reusing or recycling waste may actually generate negative emissions through these activities.[112]

Various efforts are being made to reduce greenhouse gas emissions in urban areas in low-income countries, frequently in association with broader goals of improving air quality and implementing more effective solid waste management. In Dhaka (Bangladesh), motorized rickshaws have been banned from using two-stroke petrol engines since September 2002 and have been replaced by engines using compressed natural gas.[113] Although introduced more as a measure to improve local air quality, compressed natural gas engines can reduce lifetime greenhouse gas emissions by 21 to 26 per cent.[114] Similarly, a range of interventions developed for the Dhaka Metropolitan Development Planning Support System – including environmental and physical quality, urban and infrastructure development, social and economic development, governance, and educational and scientific development – have relevance to climate change mitigation efforts.[115]

A significant proportion of urban residents in low-income countries have very low levels of GHG emissions

Estimating the global-level urban emissions

Any blanket statements about the total contribution of urban areas or cities to GHG emissions need to be treated with caution. There is no globally accepted definition of an *urban area* or *city*, and there are no globally accepted standards for recording emissions from sub-national areas. In addition, there is little clarity on the relative allocation of responsibility from production- or consumption-based approaches. This is made particularly clear in the South African cases presented above, as well as in the comparison between Japanese and Chinese cities in which vastly different proportions of emissions can be attributed to the manufacturing sector, which produces goods for consumption in many other locations around the world.

Any blanket statements about the total contribution of urban areas or cities to GHG emissions need to be treated with caution

At one extreme, it could be argued that urban areas make no contribution to GHG emissions: that the economic and social benefits, and environmental costs, associated with their commercial, industrial and manufacturing sectors are distributed more widely to individuals throughout countries, regions and around the world. In this regard, individuals or sectors could be deemed 'responsible' for certain levels of emissions. At the other extreme, it could be argued that all

Table 3.14

Cities' contribution to global anthropogenic GHG emissions, by sector

Sector	Percentage of global GHG emissions	Justification for estimating the proportion of GHGs from cities, from the perspective of the location of activities that produced them	Percentage of GHGs allocated to cities
Energy supply[a]	25.9	A high proportion of fossil fuel power stations are not in cities, especially the largest cities. One third to one half of emissions from city-based power stations.	8.6–13.0
Industry	19.4	A large proportion of heavy industry (which accounts for most GHGs from industry) is not located in cities, including many cement factories, oil refineries, pulp and paper mills, metal smelters. Two-fifths to three-fifths of emissions in cities.	7.8–11.6
Forestry[b]	17.4	No emissions assigned to cities.	0
Agriculture	13.5	Some large cities have considerable agricultural output, but mostly because of extended boundaries encompassing rural areas. No emissions assigned to cities.	0
Transport	13.1	Private use of motor vehicles a large part of this. Should commuting by car by those living outside cities be assigned to cities? Should city dwellers driving outside city boundaries be assigned to their city? 60 to 70 per cent of emissions assigned to cities.	7.9–9.2
Residential and commercial buildings	7.9	Large sections of middle- and high-income groups in developed countries live outside cities – and a significant and increasing proportion of commercial buildings are located outside cities. 60 to 70 per cent of emissions assigned to cities.	4.7–5.5
Waste and wastewater	2.8	More than half of this is landfill methane; but a proportion of this would be released outside urban boundaries from waste generated inside cities. 54 per cent of emissions assigned to cities.	1.5
Total[c]	**100**		**30.5–40.8**

Notes: a A large part of this is from fossil fuel power stations. Excludes refineries, coke ovens, etc., which are included under industry.
b Land use and land-use changes.
c Total emissions for the GHGs covered by the Kyoto Protocol amounts to 49 billion tonnes of CO_2eq.

Sources: based on Barker et al, 2007; Satterthwaite, 2008a, p544

Cities' share in ...	2006 (%)	2030 (%)
Global energy consumption	67	73
Global energy-related CO_2 emissions	71	76
Global anthropogenic GHG emissions	40–70	43–70

Source: Walraven, 2009

Table 3.15

The contribution of urban areas to various aspects of climate change

human activities other than those directly associated with rural land-use change and agriculture are urban in their character. In this situation, all non-forestry and agriculture emissions could be allocated to urban areas – which constitute 69 per cent of total global emissions according to the IPCC. Neither of these perspectives is valid – but they do highlight that 'drawing the line' as to exactly how urban areas 'contribute' to climate change is a highly subjective process.

From the perspective of the location of production, it has been suggested that *cities* (in this case, excluding smaller towns and other small urban settlements) probably emit between 30 and 40 per cent of all anthropogenic GHG emissions (see Table 3.14). This is based on an analysis of the contribution of different sectors to global emissions, and an assessment of the proportion of each of these that is associated with cities.[116] Table 3.15 provides higher estimates of the contribution of cities to global GHG emissions,[117] although, in this case, cities refer to all urban areas, including towns and other small urban settlements. It has been suggested that various overestimates of urban contributions to climate change are related to an Organisation for Economic Co-operation and Development (OECD) report, which states that 80 per cent of global energy use is linked to cities.[118] Consequently, a production-based figure of 40 to 70 per cent, and a consumption-based figure of 60 to 70 per cent has been presented.[119] The differences between consumption- and production-based approaches will be discussed in greater detail below.[120]

The climatic situation of any given urban area affects the energy demands for heating and cooling

FACTORS INFLUENCING EMISSIONS

As the previous section showed, the contribution of urban areas to GHG emissions in different countries – and even of different urban areas within the same country – varies greatly. This is due to a variety of factors, including differences in the sources of emissions.[121] This section examines the main factors that affect the sectors generating GHGs – namely, geographic situation, demographic variation, urban form and the types of economic activities. None of these factors operate in isolation, and it is perhaps more appropriate to conceptualize the urban system as a whole – recognizing that any urban area is intricately linked with rural areas, urban areas within the same country, and has international linkages. The discussion also looks at the politics of measuring GHG emissions by discussing alternative approaches, such as ecological versus carbon footprints, production-based versus consumption-based approaches, and individual versus urban drivers of emissions.

The geographical location in relation to natural resources influences the fuels that are used for energy generation and, hence, the levels of GHG emissions

Geographic situation

Various aspects of geography affect the contribution of urban areas to climate change. These can be broadly categorized as climatic situation, altitude and location in relation to natural resources. The climatic situation of any given urban area affects the energy demands for heating and cooling. High-latitude locations have longer hours of darkness in the winter, requiring additional energy consumption for lighting. High-latitude locations are also colder in winter, with additional heating requirements. Both space and water require heating, and in many countries (e.g. the UK), the heating of water is a major consumer of energy in residential households. Heating requirements are usually met through the direct burning of an energy source such as coal, oil or natural gas. In contrast, space cooling through air conditioning is normally powered by electricity. Urban areas in warmer locations therefore have an emissions profile strongly influenced by the energy source used to generate this.

In Spain, electricity demand shows an increasing trend that can be linked to demographic, social and economic factors. Within this trend, variations in consumption can be seen as a result of particular weather conditions. In the winter months, colder than normal days are associated with increased electricity consumption for heating, whereas in the summer months, warmer than normal days are associated with this for cooling.[122]

In the US, the consumption of fuel oil and natural gas by households is determined primarily by climate. There is a very strong negative correlation between home heating-related emissions and lower temperatures in January – a factor that is, itself, determined by geographical location.[123] In contrast, many locations in the US with particularly hot summers (higher temperatures in July) have higher electricity consumption associated with space cooling. Solely taking these issues into account, it has been noted that areas with moderate temperatures have lower emissions and lower associated expenditure on energy. Although comparable studies have not been undertaken elsewhere, it is likely that this pattern is replicated on a global level, with areas experiencing very hot or cold climatic conditions requiring a greater use of energy for the cooling or heating of residential and commercial buildings.

The geographical location in relation to natural resources influences the fuels that are used for energy generation and, hence, the levels of GHG emissions. This is a factor of transportation costs: where a more efficient source of fuel is available in close proximity to the city or town, it can be used more economically. For example, urban areas that are able to draw on nearby sources of natural gas will emit a smaller volume of GHGs for a given amount of energy than areas that rely on coal for energy. China's continued reliance on coal, which provides 70 per cent of its total energy requirements, is largely due to the abundance of this resource – China has the world's third largest coal reserves and is the largest coal producer in the world. In contrast, countries with larger reserves of natural gas tend to be more reliant on this cleaner source of energy. For example, the UK has increased the proportion of its energy from natural gas from 20 to 34 per cent between 1980 and 2003.[124]

The potential for using renewable sources of energy – and the reductions in GHG emissions associated with this – are also affected by locational factors. Some renewable energy is entirely reliant on natural resources – for example, the availability of large rivers for hydroelectric generation: Rio de Janeiro and São Paulo (in Brazil) have low levels of emissions from electricity generation for this reason. In other locations, particularly in smaller or more arid regions, large-scale hydroelectric generation is not a viable source of energy. Wind, geothermal, tidal and wave energy all rely on natural phenomena existing in particular locations, although solar photovoltaic and solar thermal energy are less tied to specific locations.[125]

Geographical location affects the type of economic activities taking place in urban areas. Similarly, these can both be environmental and social factors of location. Historically, heavy industry has been located close to bulky raw materials, particularly coal and iron ore. The new international division of labour, coupled with increasing reductions in cross-border tariffs, means that spatial variation in the cost of labour are increasingly important in determining the location of manufacturing activities.

The geographic level at which decisions on energy are made can also influence emissions from urban areas. Decisions to construct and operate nuclear power plants are made at the country level, rather than at the city level. Nuclear power generation – assessed purely from a GHG emissions perspective – enables reduced climate impacts from a given amount of energy; yet urban areas themselves are unable to make decisions of this nature. National policy decisions in France and Spain are one reason why city emissions in these countries are lower than those of cities in the UK.

Demographic situation

The relationship between population growth and GHG emissions is complicated, and varies according to the level of analysis. As can be seen from the wide variations in GHG emissions from countries around the world, population size in itself is not a major driver of global warming. At a global level, the areas experiencing the highest rates of population growth are areas with currently low levels of per capita emissions. As Table 3.16 shows, the developing countries with the highest rates of population growth have had much lower rates of growth in their CO_2 emissions than developed countries with much lower rates of population growth. While larger urban populations do lead to increased total sulphur dioxide emissions and transportation energy use,[126] there is no evidence to suggest that this results in higher per capita emissions. Table 3.16 also shows that the increase in CO_2 emissions in high-income countries has been significantly higher than in the upper-middle income countries, despite relatively similar rates of population growth.

The demographic composition of a society has a wide range of effects on consumption behaviour and GHG emissions. In some urban areas, changing age structures will affect GHG emissions associated with energy use. Population aging in the US has been shown to cause reductions in labour income and changes in consumption patterns – both of which result in lower GHG emissions. Depending on the factors taken into consideration, these savings can range from 15 to 40 per cent of the emissions that would otherwise be expected. Conversely, in China, estimates of GHG emissions that incorporate aging suggest that this will initially lead to higher emissions (as the proportion of the population in the labour force and, hence, their power to consume increases), followed by reduced emissions (as this proportion declines).[127]

Income category in 2005	1950–1980		1980–2005	
	Growth in population (%)	Growth in CO_2 emissions (%)	Growth in population (%)	Growth in CO_2 emissions (%)
Low-income countries	36.0	5.6	52.1	12.8
Lower-middle income countries	47.1	39.7	35.7	53.2
Upper-middle income countries	5.7	9.6	5.0	5.0
High-income countries	11.2	45.1	7.2	29.1

Source: Satterthwaite, 2009, p558

Table 3.16

CO_2 emissions, population growth and national income

Another demographic change that may affect patterns of GHG emissions from urban areas is the increasing trend towards smaller households. In many developed countries and some developing countries such as China, the average household size has declined – meaning that the number of households has expanded more rapidly than the total population size. Economies of scale are therefore reduced, with the result that the per capita energy consumption of smaller households is significantly higher than that of larger households.[128]

Per capita energy consumption of smaller households is significantly higher than that of larger households

Paradoxically, the slowing of population growth may result in increased emissions, as lower population growth and smaller household sizes may be associated with a rise in the number of separate households and increased disposable income to be spent on consumption. The decline in fertility in Brazil has been associated with a rapid rise in the number of households. The total fertility rate declined from six births per woman during the mid 1960s to replacement level in the mid 2000s. While the population grew at an annual rate of 1.4 per cent between 1996 and 2006, the actual number of households increased at an annual rate of 3.2 per cent. Over the same time period, the number of 'double income no kids' households almost doubled (from 1.1 million to 2.1 million). These households have relatively high incomes and the ability to consume larger quantities of goods and services with associated consequences for their total GHG emissions.[129]

Paradoxically, the slowing of population growth may result in increased emissions, as lower population growth and smaller households sizes may be associated with a rise in the number of separate households and increased disposable income to be spent on consumption

The relationship between population size, population composition and the contribution of urban areas to climate change is therefore complex. As cities grow, they concentrate the demand for fresh water and other natural resources, and concentrate the production of pollutants and GHGs. Cities with considerable local ecological impact – such as Solapur, India, with 1.1 million people but low average consumption – may have much smaller global impacts than similar-sized cities (such as Perth, Australia, or Portland, US). These latter cities have moderated their local ecological impact by importing most of the goods that they consume – potentially producing far larger global impacts.[130]

Taking this into account, it is not the absolute number of people who live in urban areas that affects the contribution of these areas to climate change. Rather, it is the way in which these areas are managed, and the choices that are made by the urban residents living there that have the greatest effects.

Urban form and density[131]

There is strong evidence that urban densities have been declining over the past two centuries

Urban form and density are associated with a range of social and environmental consequences. On the one hand, the extremely high densities of many cities in developing countries – particularly in informal settlements and other slums – result in increased health risks, and high levels of vulnerability to climate change and extreme events. At the other extreme, the extremely low densities of many suburban areas in North America are associated with high levels of household energy consumption as a result of sprawling buildings and extensive car usage.

Urban sprawl refers to the increasing geographical spread of urban areas into areas that were not previously built up.[132] In many developing countries, the related process of peri-urbanization is increasingly taking place.[133] These interfaces are affected by some of the most serious problems of urbanization, including intense pressures on resources, slum formation, lack of adequate services such as water and sanitation, poor planning, and degradation of farmland. They are of particular significance in developing countries, where planning regulations may be weak or weakly enforced, and result in areas with complex patterns of land tenure and land use.

Spatially compact and mixed-use urban developments have several benefits in terms of GHG emissions

At its simplest, urban density is measured by dividing a given population by its area. In the case of urban areas, the widely varying definitions of the spatial extent of these areas lead to a great deal of difficulty in generating comparable statistics for different towns and cities. Dividing the population of a metropolitan area by the administrative area contained within its official boundaries is a highly unreliable measure – particularly for comparisons – because the density will vary according to the definition of these boundaries.[134] In addition, standard measures of density are calculated over an entire land area, without taking into account the levels of connectivity. In this regard, the gradual transformation of the urban form of Curitiba (Brazil) from a predominantly radial-circular form to a more linear pattern of development has reduced the city's overall density, yet has facilitated the development of a more rapid and effective public transportation system and various other social and environmental benefits.[135]

In general and at a global level, there is strong evidence that urban densities have been declining over the past two centuries.[136] Perhaps the most detailed and compelling assessment of this phenomenon is provided by a World Bank report that records the decline in the average density of developed country cities from 3545 to 2835 people per square kilometre between 1990 and 2000. During the same period, the average urban population density in developing countries declined from 9560 to 8050 people per square kilometre.[137] The reduction in urban densities is likely to continue into the future. It is estimated that the total population of cities in developing countries will double between 2000 and 2030; but their built-up areas will triple from approximately 200,000 square kilometres to approximately 600,000 square kilometres. During the same period, the population of cities in developed countries is projected to increase by approximately 20 per cent, while their built-up areas will increase by 2.5 times: from approximately 200,000 square kilometres to approximately 500,000 square kilometres. These agglomerated figures for developed and developing countries conceal a great deal of regional variation (see Table 3.17). Southeast Asian cities were almost four times as densely populated as European cities, and almost eight times as densely populated as those in North America and Australasia. When disaggregated by national income levels, Table 3.17 shows that cities in low-income countries are more than four times as densely populated as cities in high-income countries.

In summary, spatially compact and mixed-use urban developments have several benefits in terms of GHG emissions:

- Reduced costs for heating and cooling resulting from smaller homes and shared walls in multi-unit dwellings (see above).
- The use of energy systems covering a broader area (e.g. district) for cooling, heating and power generation, as well as lesser line losses related to electricity transmission and distribution. The use of micro-grids to meet local requirements of electricity can create efficiencies in storage and distribution.[138]
- Reduced average daily vehicle kilometres travelled in freight deliveries and by private motor vehicles per capita. Population density increases accessibility to such destinations as stores, employment centres and theatres.[139] It has been found that with all other variables constant except density, a 'household in a neighbourhood with 1000 fewer units per square mile drives almost 1200 miles more and consumes 65 more gallons of fuel per year' over a household in a higher density neighbourhood.[140]

Table 3.17

Average population density of cities' built-up areas

Region	Persons per square kilometre 1990	Persons per square kilometre 2000
Developed countries	3545	2835
Europe	5270	4345
Other developed countries	2790	2300
Developing countries	9560	8050
East Asia and the Pacific	15,380	9350
Latin America and the Caribbean	6955	6785
Northern Africa	10,010	9250
South and Central Asia	17,980	13,720
Southeast Asia	25,360	16,495
Sub-Saharan Africa	9470	6630
Western Asia	6410	5820
High-income countries	3565	2855
Upper-middle income countries	6370	5930
Lower-middle income countries	12,245	8820
Low-income countries	15,340	11,850

Source: adapted from Angel et al, 2005

Urban density and greenhouse gas emissions

Urban form and urban spatial organization can have a wide variety of implications for a city's GHG emissions. The high concentrations of people and economic activities in urban areas can lead to economies of scale, proximity and agglomeration – all of which can have a positive impact upon energy use and associated emissions, while the proximity of homes and businesses can encourage walking, cycling and the use of mass transport in place of private motor vehicles.[141] Some researchers suggest that each doubling of average neighbourhood density is associated with a decrease of 20 to 40 per cent in per-household vehicle use with a corresponding decline in emissions.[142] An influential paper published in 1989 suggested that gasoline use per capita declines with urban density, although this relationship weakens once GDP per capita is brought into consideration.[143] It has also been argued that 'by the middle of the century the combination of green buildings and smart growth could deliver the deeper reductions that many believe are needed to mitigate climate change'.[144]

A recent study of GHG emissions in Toronto (Canada) deals with the issue of density explicitly. The study depicts both the overall patterns of GHG emissions and examines how these vary spatially throughout the Toronto Census Metropolitan Area: as the distance from the central core increases, private motor vehicle emissions begin to dominate the total emissions.[145] This pattern is supported by an earlier study, which found that low-density suburban development in Toronto is 2 to 2.5 times more energy and GHG intensive than high-density urban core development on a per capita basis.[146]

Density may also affect household energy consumption. More compact housing uses less energy for heating. For example, households in the US living in single-family detached housing consume 35 per cent more energy for heating and 21 per cent more for cooling than comparable households in other forms of housing. In addition, dense urban areas generate a more intense urban heat-island effect[147] that raises air temperature in a typical US city by 1°C to 3°C over the surrounding rural area. This increases the number of 'cooling days' and decreases the number of 'heating days', with the latter tending to have a greater effect on energy consumption. Consequently, residential buildings in dense urban areas tend to consume lower levels of energy.[148]

Any assessment of changing density and changing emissions needs to take multiple factors into account. It is necessary to assess the GHG emissions of different types of urban development both between different cities and within the same city. While it appears that decreasing urban density may be implicated in increasing GHG emissions, the data are affected by a variety of other variables, including overall income levels. For example, cities in South Asia are not only more densely settled than cities in North America, but also have much lower GHG emissions. The difference in the latter is due much more to income and consumption patterns than to variations in income levels. For example, London's annual emissions declined from 45.1 to 44.3 million tonnes between 1990 and 2006, despite the population growing by 0.7 million people, the built-up area increasing from 1573 to 1855 square kilometres, and urban density decreasing from 6314 to 5405 persons per square kilometre.[149] In this particular situation, per capita GHG emissions appeared to decline at the same time as urban density declined. While it may appear that the decreased density did not influence GHG emissions, in fact the decline in emissions can be attributed to the halving of industrial emissions, as industrial activity has relocated to other parts of the UK or overseas.

Dense urban settlements can therefore be seen to enable lifestyles that reduce per capita GHG emissions through the concentration of services that reduces the need to travel large distances, the better provision of public transportation networks, and the constraints on the size of residential dwellings imposed by the scarcity and high cost of land. Yet, conscious strategies to increase urban density may or may not have a positive influence on GHG emissions and other environmental impacts. Many of the world's most densely populated cities in South, Central and Southeast Asia suffer severely from overcrowding, and reducing urban density will meet a great many broader social, environmental and developmental needs. However, people do often wish to stay in the same location, and improvements can be achieved through upgrading. High urban densities can cause localized climatic effects, such as increased local temperatures.[150] In addition, a variety of vulnerabilities to climate change are also exacerbated by density. Coastal location, exposure to the urban heat-island effect, high levels of outdoor and indoor air pollution, and poor sanitation are associated with areas of high population density in developing country cities.[151] However, these also provide clear opportunities for simultaneously improving health and cutting GHG emissions through policies related to transport systems, urban planning, building regulations and household energy supply.[152]

However, it should be noted that density is just one of a variety of factors that influences the sustainability of urban form. It has been argued that compactness alone is neither a necessary nor sufficient condition for sustainability,[153] and at least seven design concepts for a sustainable urban form have been identified – namely, compactness, sustainable transport, density, mixed land uses, diversity, passive solar design, and greening.[154] Based on these criteria, the 'compact city' model is identified as being most sustainable, followed by the 'eco-city', 'neo-traditional development' and 'urban containment' – although this classification and ranking is based on reviews of literature rather than empirical research. A more complex relationship between land use and GHG emissions involves a model that also takes into account landscape impacts (deforestation, carbon sequestration by soils and plants, urban heat island), infrastructure impacts, transportation-related emissions, waste management-related emissions, electric transmission and distribution losses, and buildings (residential and commercial). There are complex relationships between these factors – for example, denser residential areas may have lower levels of car use, but simultaneously present fewer options for carbon sequestration.[155]

The high concentrations of people and economic activities in urban areas can lead to economies of scale, proximity and agglomeration – all of which can have a positive impact upon energy use and associated emissions

Dense urban settlements … enable lifestyles that reduce per capita GHG emissions

Conscious strategies to increase urban density may or may not have a positive influence on GHG emissions and other environmental impacts

Although the relationship between urban density and GHG emissions is complex, there are certain directions that can be identified that are of relevance for urban policy. These do not amount to wholesale recommendations in favour of densification, but rather look at strategically assessing population distributions in a manner that contributes to broader goals of climate change mitigation. Encouraging densification at an aggregate level – for example, within administrative boundaries – risks neglecting the important environmental and social roles played by gardens and open spaces. It is also worth considering the different housing needs for individuals at different life stages, and reconsidering the notion of 'housing for life' that has been prevalent in many national housing policies. In this regard, dense settlement patterns may meet the needs of certain groups within society, but not others.

In general, density provides the potential for access to and greater use of public transport and of walking and cycling

In general, density provides the potential for access to and greater use of public transport and of walking and cycling – where urban space is designed to meet the needs of users. A study of London shows a 'positive link between higher density areas and levels of public transport access across London, which is reflected in the decisions that people make about how to get to work'.[156] It further concludes that 'on balance, people will use public transport where it is available, especially in high density, centrally located areas'. People appear willing to 'trade off' more space in their home for other qualities of a residential area, including personal and property safety, the upkeep of the area, and proximity to shops and amenities.

Urban spatial structures play a major role in determining … the transportation mode … and with it cities' levels of energy use and GHG emissions.

Localized areas of relatively high densities are required to generate greater efficiencies in the usage of public transportation; but this can be consistent with meeting a variety of other demands from urban residents. Of course, the precise form that these transportation networks – and other urban networks for supplying electricity, water, etc. – should take requires detailed local study. Overall, density is one of several factors that affects energy use (and, by extension, GHG emissions) from towns and cities. Addressing these issues requires ongoing analysis of urban *processes* rather than simply taking a snapshot of urban *form* at a particular moment in time.

The types of economic activities that take place within urban areas … influence GHG emissions

The uses of land and spatial distribution of population densities within an urban area define its *structure* or *form*. Urban spatial structures play a major role in determining not only population densities, but also the transportation mode (e.g. the relative importance of public versus private modes) and with it cities' levels of energy use and GHG emissions. While urban structures do evolve with time, driven by changes in the localization of economic activities, real estate developments and population, their evolution is slow and can seldom be shaped by design. The larger the city, the less it is amenable to change its urban structure.

Four urban structures or forms can be distinguished.[157] In the first, *mono-centric*, represented by such cities as New York (US), London (UK), Mumbai (India) and Singapore, most economic activities, jobs and amenities are concentrated in the central business district (CBD). Here authorities should focus on promoting public transport as the most convenient transport mode, for most commuters travel from the suburbs to the CBD. In the second, *poly-centric*, exemplified by such cities as Huston (US), Atlanta (US) and Rio de Janeiro (Brazil), few jobs and amenities are located in the centre and most trips are from suburb to suburb. A very large number of possible travel routes exists, but with few passengers per route. Therefore public transport is difficult and expensive to operate and individual means of transportation or collective taxis are and should be promoted as the more convenient transportation options for users. The third one, *composite (or multiple-nuclei) model*, is the most common type of urban spatial structure containing a dominant centre together with a large number of jobs located in the suburbs. Most trips from the suburbs to the CBD are made and should be promoted by public transport, while trips from suburb to suburb are made with individual cars, motorcycles, collective taxis or minibuses. The fourth, also called *urban village model*, does not exist in the real world, but can be found only in urban master plans. In this model, urban areas contain many business centres, commuters travel only to the centre which is the closest to their residence and have more opportunities to walk or bicycle to work. It is an ideal because it requires less transportation and roads, thus, in theory, dramatically reducing distances travelled, energy used and, as a consequence, emissions of GHGs and other pollutants. However it is not feasible, as 'it implies a systematic fragmentation of labour markets which would be economically unsustainable in the real world'.[158]

The urban economy

The types of economic activities that take place within urban areas also influence GHG emissions. Extractive activities (such as mining and lumbering) and energy-intensive manufacturing are obviously associated with higher levels of emissions – especially when the energy for these is supplied from fossil fuels. However, there are fewer of these activities in many cities in developed countries, as lower transportation costs and the lower cost of labour elsewhere have encouraged industries to relocate elsewhere. In London, for example, industrial emissions halved between 1990 and 2006, as industrial activity has relocated to other parts of the UK or overseas.[159]

Yet, all urban areas rely on a wide range of manufactured goods (produced within the urban area or elsewhere), and manufacturing areas similarly rely on the services provided by certain urban centres. This relationship can exist within countries. In South Africa (and as noted above), the industrial town of Sedibeng (population of 880,000 and annual per capita emissions of 28.6 tonnes CO_2eq) is linked with the services provided by the City of Johannesburg (population 3.6 million and annual per capita emissions of 5.6 tonnes CO_2eq) (see Table 3.13). As described above, this process exists across national boundaries with many of the world's cities acting as centres for the trading of commodities and consumption of manufactured goods, while generating few emissions from within their own boundaries. With this in mind, the next section examines alternative approaches on how to measure the emissions from urban areas.

The influence of the urban economy on patterns of emissions can be seen in the large variations in the proportion of a city's GHG emissions that can be attributed to the industrial sector.[160] Industrial activities in many rapidly industrializing developing countries (such as China) are responsible for a large proportion of urban GHG emissions. Indeed, while 12 per cent of Chinese emissions were due to the production of exports in 1987, this figure had increased to 21 per cent in 2002 and 33 per cent (equivalent to 6 per cent of total global CO_2 emissions) in 2005.[161] A recent paper on this issue describes the situation as follows:

> *… many of the countries in the western world have dodged their own carbon dioxide emissions by exporting their manufacturing to … China. Next time you buy something with 'Made in China' stamped on it, ask yourself who was responsible for the emissions that created it.*[162]

In contrast, GHG emissions from the industrial sector in cities elsewhere are much lower, generally reflecting a transition to service-based urban economies. Industrial activities account for just 0.04 per cent in Washington, DC (US) (largely because of the narrow spatial definition of the District of Columbia); 7 per cent in London (UK); 9.7 per cent in São Paulo (Brazil); and 10 per cent in Tokyo (Japan) and New York City (compared to 29 per cent for the US as a whole). The declining importance of industry in causing emissions is evident in several cities. In Rio de Janeiro, the industrial sector's proportion of emissions declined from 12 per cent in 1990 to 6.2 per cent in 1998; and in Tokyo, it declined from 30 to 10 per cent during the last three decades.[163]

The politics of measuring emissions

There are striking differences in the contribution of different urban areas to climate change. Measured purely in terms of direct emissions per person from a given urban area, these may vary by a factor of 100 or more. As noted earlier in this chapter, different 'scopes' of emissions may be taken into account[164] (see Tables 3.2 and 3.4). In practice, GHG emission inventories from urban areas that include Scope 3 emissions are very rare. And the extent to which these Scope 3 emissions (i.e. indirect or embodied emissions) are included is very arbitrary and there is no agreement as to a comparable framework to compare emissions of this type between urban areas. If Scope 3 or embodied emissions are included, it is likely that the per capita emission of GHGs allocated to a city will increase significantly – particularly if the city is large, well-developed and with a predominance of service and commercial activities.[165] In addition, it is almost impossible to compile a comprehensive inventory of Scope 3 emissions that takes into account all the consumption of the individuals living in an urban area. In other words, '*emissions can be attributed either to the spatial location of actual release or to the spatial location that generated activity that led to the actual release*'.[166] A detailed Scope 3 inventory should also subtract the embodied energy in goods made in that city and subsequently exported.

The data presented in this chapter show that urban areas with a heavy concentration of industrial and manufacturing activities have high levels of GHG emissions. They also show that wealthier urban areas have high emissions – although these may be lower than non-urban but equally wealthy areas. The per capita emissions of GHGs by individuals including those caused by the goods they consume and wastes they generate vary by a factor of more than 1000 depending on the circumstances into which they were born and their life chances and personal choices. Obviously, their lifetime contribution is also influenced by how long they live. Poorer groups with low annual per capita emissions often have life expectancies of 20 to 40 years less than high-income groups. Unsustainable levels of consumption, which drive the processes of production, are therefore crucial to understanding the contribution of urban areas to climate change. This section thus discusses alternative approaches on how to calculate the contribution of urban areas to climate change, thereby helping to provide a framework for understanding and addressing the root causes of GHG emissions.

As noted above, urban areas in different countries, and even within the same country, have different emissions profiles according to environmental, economic, social, political and legal differences over space and across national boundaries. This influences the balance of *production* and *consumption* of GHGs, as many of the most highly emitting activities have been displaced to rapidly industrializing developing countries. The Kyoto Protocol – and its likely successor treaty – also creates incentives for developed countries[167] to reduce the emissions from within their national boundaries, which may create perverse incentives for raised levels of emissions in developing countries which are not subject to these constraints. However, the principle of 'common but differentiated responsibilities'[168] adopted in the negotiations ought to prevent this from happening. Similarly, as the concept of 'nationally appropriate mitigation actions'[169] becomes adopted at the local level, positive incentives may be created to encourage urban areas to reduce their emissions in contextually appropriate ways.

In particular, political forces and the policy environment – at the global, national and local levels – can be a strong underlying factor in shaping GHG emissions. At the global level, the establishment of national targets for developing countries[170] is an important factor driving reductions in emissions. The implementation of CDM projects – in which emissions reductions in developing countries are supported by developed country actors – can also shape emissions patterns. Where local and national governments in developing countries support CDM activities,[171] this can have a substantial local impact upon local emissions. At the same time, local governments can shape city emissions through several different pathways: through undertaking emissions reductions activities in their own activities (e.g. local authority buildings and vehicle fleets); through changing the legislative environment (e.g. through increased taxation on highly polluting industries or tax incentives

Industrial activities in many rapidly industrializing developing countries (such as China) are responsible for a large proportion of urban GHG emissions

In contrast, GHG emissions from the industrial sector in cities elsewhere are much lower, generally reflecting a transition to service-based urban economies

The per capita emissions of GHGs by individuals … vary by a factor of more than 1000 depending on the circumstances into which they were born and their life chances and personal choices

Political forces and the policy environment … can be a strong underlying factor in shaping GHG emissions

encouraging the use of low-carbon technology); and through encouraging behavioural change among citizens (e.g. through mass awareness or educational programmes).[172]

Ecological footprints versus carbon footprints

One useful approach for calculating GHG emissions from urban areas is to consider ecological footprints. The ecological footprint is a concept that measures the area of the Earth's surface required to provide the consumption needs of an individual, urban area or country. The concept of the ecological footprint recognizes that larger areas of land are required to sustain life inside urban areas than are contained within municipal boundaries of the built-up area – with this area being much larger for wealthy cities.[173] Most cities and regions depend on resources and ecological services – including food, water and the absorption of pollutants – from outside their boundaries; many depend on those from distant ecosystems; and the environmental consequences of urban activities are thus felt globally or in distant regions. Ecological footprint analysis has been used in recent years to develop a related concept: the carbon footprint (see Box 1.1). A full carbon footprint therefore takes into account all the emissions included in 'Scope 1', 'Scope 2' and 'Scope 3', but places a greater emphasis on the indirect emissions from products and services that are consumed but not directly controlled.

The use of a consumption-based analysis of emissions … will help to make it clearer which countries, urban areas and individuals are responsible for more than their fair contribution to global climate change

Although often used interchangeably, the implications of an emissions inventory and a carbon footprint can therefore be quite different. The *emissions inventory* is derived from the UNFCCC model of national inventories that accounts for GHG emissions produced within a geographically defined boundary. In contrast, the *carbon footprint* is derived from the concept of the ecological footprint, and is focused on the GHG emissions associated with the consumption of goods and services. The origin of GHG emissions is therefore better understood through the use of consumption-based assessments. In relation to ecological footprints, it has been concluded that 'wealthy nations appropriate more than their fair share of the planet's carrying capacity'.[174] Similarly, the use of a consumption-based analysis of emissions, derived from a carbon footprint approach, will help to make it clearer which countries, urban areas and individuals are responsible for more than their fair contribution to global climate change.

From the perspective of global climate change, the consequences are the same irrespective of whether an industry is located within the urban areas or rural areas of a developed or a developing country

Production-based versus consumption-based approaches

The use of a production-based approach to assessing the contribution of urban areas to GHG emissions can lead to perverse and negative effects. Urban areas will be able to *reduce* their emissions through creating disincentives for *dirty* economic activities that generate high levels of GHGs (e.g. heavy industry), and incentives for *clean* economic activities that generate much smaller emissions (e.g. high-tech industries). This situation can already be seen: many polluting and carbon-intensive manufacturing processes are no longer located in Europe or North America, but have been sited elsewhere in the world to take advantage of lower labour costs and less rigorous environmental enforcement. Since developing countries are not required to reduce emissions under the UNFCCC, a process of 'carbon leakage' can take place, where emissions are moved rather than reduced.[175] Yet, climate change is a global phenomenon: emissions of a given quantity of CO_2 have the same effect on the global climate wherever in the world these are released. From the perspective of global climate change, the consequences are the same irrespective of whether an industry is located within the urban areas or rural areas of a developed or a developing country. The underlying drivers for these emissions are the demands of consumers who desire particular products. Thus, an assessment of the contribution of urban areas to climate change needs to reflect the location of the people making these demands.

At a national level, input–output analyses have been used to show national average per capita carbon footprints. These take into account construction, shelter, food, clothing, mobility, manufactured products, services and trade. National average per capita footprints vary from approximately 1 tonne CO_2eq in many African countries to approximately 30 tonnes CO_2eq in Luxembourg and the US. The proportion of these emissions attributed to internal consumption varies greatly: with low figures in small city-states and countries with low levels of imports (e.g. 17 per cent in Hong Kong and 36 per cent in Singapore) and high figures in major industrial and manufacturing countries (e.g. 94 per cent in China and 95 per cent in India) and in countries with low levels of imports as a result of poverty (e.g. 90 per cent in Madagascar and Tanzania).[176] This method for measuring *responsibility* shows clearly that the countries with high levels of consumption and imports are responsible for much greater volumes of GHG emissions than a production-based approach would indicate.

Production-based emissions methodologies … distort the responsibility of different cities for generating GHGs

The use of a production-based system to assess the contribution of urban areas to climate change diverts attention and blame from the high-consumption lifestyles that drive unsustainable levels of GHG emissions. This system fails to identify the areas in which interventions are required to reduce emissions by focusing attention on only one part of multiple complex commodity chains. In addition, analysing emissions at a city level generates a variety of logistical problems. For instance, there are large information gaps (particularly in developing countries); different information is available at different geographic levels; and political boundaries of cities may change over time and often include both rural and urban populations (as is the case for Beijing and Shanghai in China).[177]

Production-based emissions methodologies therefore distort the responsibility of different cities for generating GHGs. Different types of cities will be affected in different ways by this approach: 'in service-oriented cities, consumption-related emissions are more important than those produced by production'.[178] Consequently, the responsibility of successful production-oriented centres such as Beijing and Shanghai is exaggerated, while that of wealthy service-oriented cities including many cities in North America and Europe is underemphasized. The fact that Beijing and Shanghai have per capita emissions of more than twice the

Chinese average therefore reflects not only the relative affluence of these cities (and the spatially uneven incorporation of different parts of China into global economic networks), but also the role that they play in manufacturing consumer products that are used elsewhere in China and throughout the world.

In contrast, a consumption-based approach attempts to address the origin of emissions in a more comprehensive manner. This type of accounting system would result in a lower level of GHG emissions to developing countries (with a likely substantial reduction in the GHG emissions allocated to China and Chinese cities), and should – in theory – influence consumers in developed countries to assume responsibility for choosing the best strategies and policies to reduce emissions.[179] Consumption-based mechanisms inherently have greater degrees of uncertainty (as there are many more systems to be incorporated in the final calculation); but they do provide considerable insight into climate policy and mitigation, and should probably be used at least as a complementary indicator to help analyse and inform climate policy.[180] They respond to broader concerns about sustainability by ensuring that as well as improving environmental performance within city boundaries, there is a reduction in the transfer of environmental costs to other people, distant places or future times.[181]

A consumption-based approach can also be benchmarked against global needs to limit GHG emissions to prevent dangerous climate change. The best available estimates suggest that annual global GHG emissions need to be reduced from approximately 50 billion tonnes to 20 billion tonnes CO_2eq per year by 2050. With an estimated global population of 9 billion in 2050, this means that individual carbon footprints around the world will have to be at an average of less than 2.2 tonnes per year. In particular, it must be recognized that different locations have access to different sources of energy: and a *fair* allocation of emissions should not mean that individuals or urban areas located in geographical proximity to abundant geothermal or hydroelectric sources of energy are able to *cash in* these spatial advantages to produce greater emissions from other activities. Climate change is, indeed, a global challenge, and needs to be addressed with global solutions.

Recent research has highlighted the role of urban food consumption in generating GHG emissions. The processes involved in the production and distribution of food for urban consumption use significant amounts of energy and also generate substantial GHG emissions. Fruits and vegetables consumed in developed countries often travel between 2500km and 4000km from farm to store.[182] In North America, for example, the average food product in the supermarket has travelled 2100km before ending up on a shelf and the food system accounts for some 15 to 20 per cent of the energy consumption in the US.[183] Research has also shown that a basic diet composed of imported ingredients can use four times the energy and produce four times the GHG emission than an equivalent diet with local ingredients. The potential for localized urban food production and consumption in promoting energy efficiency and reducing GHG emissions is clear.

However, this needs to be seen alongside the development benefits that the export of agricultural products can bring to developing countries. Air-freighted products are frequently seen as major problems in the emission of GHGs; yet the issues are much more complex. In the UK, fresh produce air-freighted from Africa is responsible for less than 0.1 per cent of national emissions – and the emissions from sub-Saharan African countries are minuscule in the first place. At the same time, more than 1 million African livelihoods are supported by growing this produce.[184] In addition, some agricultural practices that reduce 'food kilometres' – such as using greenhouses to grow tropical crops in temperate latitudes – can have a larger impact upon emissions than the distance travelled.

Distinct challenges are associated with consumption-based approaches to measuring the contribution of individuals and urban areas to climate change; yet these can provide considerable insights into climate policy and mitigation.[185] In practice, both production- and consumption-based approaches will continue to be required. Table 3.18 shows the main driving forces for GHG emissions from both perspectives. In many sectors – particularly in energy, transport, and residential and commercial buildings – interventions to address production-related emissions are similar to those addressing consumption-related emissions. In terms of industry, however, a consumption-based approach places an added emphasis on the global dimensions of emissions – spreading the net wider in terms of where the impacts of individual activities are actually felt. Addressing emissions from a consumption-based approach is therefore much more about reducing emissions rather than merely shifting them elsewhere.

Consumption-based approaches help to ensure that the allocation of responsibility for GHG emissions simultaneously addresses concerns of climate, environmental and gender justice. Of course, global action is required to reduce the risks of climate change – yet the burden for meeting this goal should not fall on individuals or urban areas that have little responsibility for it.[186] Rather, a consumption-based analysis ensures that the responsibility for addressing this problem lies with the individuals, urban areas and countries who have the greatest responsibility for causing it. Similarly, production-based inventories mask the gendered nature of individual energy-use patterns.[187] Indeed, one study suggests that more men than women own cars in Sweden, and concludes that 'if women's consumption levels were to be the norm, both emissions and climate change would be significantly less than today'.[188]

Individual versus urban drivers of emissions

The preceding discussion makes it clear that consumption is perhaps the most important driver of GHG emissions. In this regard, individuals can be seen as the basic unit affecting emissions. It is the consumption choices and behaviour of individuals that ultimately lead to the use of energy and the production of GHGs. However, it needs to be stressed that the choices that individuals make are shaped by structural forces in the areas in which they live. For example, individuals living in urban areas with effective integrated public

Consumption-based mechanisms … respond to broader concerns about sustainability by ensuring that … there is a reduction in the transfer of environmental costs to other people, distant places or future times

Climate change is … a global challenge, and needs to be addressed with global solutions

Consumption-based approaches help to ensure that the allocation of responsibility for GHG emissions simultaneously addresses concerns of climate, environmental and gender justice

Table 3.18

Urban GHG emissions: Production versus consumption perspectives

Sector	What drives growing GHG emissions in urban areas?	
	Production perspective	Consumption perspective
Energy supply:	A large proportion comes from fossil fuel power stations – hence, a growth in electricity provision from high GHG-emitting sources. Many large fossil fuel power stations are located outside urban areas; but the GHG emissions from the electricity used in urban areas are usually allocated to these urban areas.	GHGs from energy supply now assigned to consumers of energy supplies/electricity, so growth in GHG emissions is driven by increasing energy use; consumers are also allocated the GHGs from the energy used to make and deliver the goods and services that they consume.
Industry:	Growing levels of production; growing energy intensity in what is produced; importance of industries producing goods whose fabrication entails large GHG emissions (e.g. motor vehicles).	GHGs from industries and from producing the material inputs that they draw on no longer allocated to the enterprises that produce them, but rather to the final consumers of the products, so again GHG growth driven by increased consumption.
Forestry and agriculture:	Many urban centres have considerable agricultural output and/or forested areas, but mostly because of extended boundaries that encompass rural areas; from the production perspective, GHGs generated by deforestation and agriculture are assigned to rural areas.	GHGs from these no longer allocated to rural areas (where they are produced), but rather to the consumers of their products (many or most in urban areas); note how energy intensive most commercial agriculture has become; also the high GHG implications for preferred diets among high-income groups (including imported goods, high meat consumption, etc.).
Transport:	Growing use of private motor vehicles; increases in average fuel consumption of private motor vehicles; increased air travel (although this may not be allocated to urban areas).	As in the production perspective; GHG emissions from fuel use by people travelling outside the urban area they live in are allocated to them (thus, includes air travel); also concern for GHG emissions arising from investment in transport infrastructure.
Residential/ commercial buildings:	Growth in the use of fossil fuels and/or growth in electricity use from fossil fuels for space heating and/or cooling, lighting and domestic appliances.	As in the production perspective, but with the addition of GHG emissions arising from construction and building maintenance (including the materials used to do so).
Waste and wastewater:	Growing volumes of solid and liquid wastes and of more energy-intensive waste.	Large and often growing volumes of solid and liquid wastes with GHGs; these are allocated to the consumers who generated the waste, not to the waste or waste dump.
Public sector and governance:	N/A	Conventional focus of urban governments on attracting new investment, allowing urban sprawl and heavy investment in roads, with little concern for promoting energy efficiency and low GHG emissions.

Notes: For a discussion of mitigation action based on these two perspectives, see Table 5.11. N/A = not available.

Source: based on Satterthwaite, 2009, pp548–549

transportation systems or safe, well-maintained bicycle pathways will be much more able to reduce distances travelled by car. As an increasing proportion of the world's population lives in urban areas, the choices that are made in relation to investments in urban infrastructure will have a growing role in determining future GHG emissions.

High levels of wealth and disposable income lead to generally high levels of consumption and, hence, GHG emissions

In developed countries, high levels of wealth and disposable income lead to generally high levels of consumption and, hence, GHG emissions, as is evident from some of the national inventories discussed earlier in this chapter.[189] As was also discussed, the economies of scale and the advantages of density mean that urban residents in these countries tend to generate fewer GHG emissions than the national average – at least from a production perspective. Individual drivers of emissions in urban areas in developed countries are still – obviously – related to personal consumption habits. Yet, at the same time, the consumption patterns of wealthy residents in developing countries also drive up national GHG emissions. It should also be noted that in developing countries, average incomes in urban areas are often substantially higher than in rural areas. Individuals and households with higher incomes – and greater consumption – are therefore likely to be concentrated in these urban areas.

Women tend to contribute less to climate change as an outcome of consumption patterns, social roles and pro-environmental behaviour

The behaviour of urban residents is shaped by cultural and social contexts. These factors can drive individual choices that affect emissions, including the choice of car, decisions about transportation modes and the ways in which energy is used at home (switching off lights, managing heating and cooling), all of which can make a difference to urban emissions.[190] More broadly, the values placed on leading more self-sufficient lives can affect a wide range of consumption decisions and, therefore, emissions generation.

These contexts include gender roles and expectations. On average, women tend to contribute less to climate change as an outcome of consumption patterns, social roles and pro-environmental behaviour.[191] In general, people living in poverty tend to contribute less to climate change, and more women than men in almost all societies live in poverty. Prescribed gender roles mean that women tend to participate in different activities than men, and frequently travel less for business purposes. In addition, there is evidence that women in developed countries are more likely to consider the environmental impact of purchasing decisions. However, this analysis needs to be tempered by the fact that for various activities – particularly household services such as heating and food preparation – it is impossible to disaggregate the relative contribution of different members within the same household. Yet, despite their lower contribution to climate change, women are more likely to be affected by its impacts.[192]

However, these individual choices need to be seen in the context of the provision (or lack) of particular forms of infrastructure that can lead to marked differences in urban emissions. The same per capita electricity consumption can give widely diverging per capita GHG emissions based on the energy pathways adopted at the urban and national level. Among the factors leading to Tokyo's lower emissions than those in Beijing and Shanghai are its efficient urban infrastructure, greater reliance on lower-emitting sources of energy generation, and more efficient end-use technology, as well as the different types of industrial activities taking place.[193] Independently of the level of affluence, a well-managed city with a good public transportation system, whose population has access to water and sanitation, to adequate health services and to a good quality of life, is likely to have fewer problems in dealing with a wide range of environmental challenges – including climate change – than a city that is poorly managed.

Most US cities have three to five times the gasoline use per person of most European cities; yet it is difficult to see that Detroit has five times the quality of life of Copenhagen or Amsterdam. Indeed, wealthy, prosperous and desirable cities can have relatively low levels of fuel consumption per person.[194] Most European cities have high-density centres where walking and bicycling are efficient and pleasant modes of transport and public transportation is often well-planned and effective. In this regard, well-planned and well-governed cities are central to delinking high living standards and high quality of life from high consumption and high GHG emissions.[195]

However, it should be remembered that cities and towns also contain areas that have high concentrations of poverty and vulnerability, and many residents of these areas will have extremely low emissions. For low-income households in most developing countries, recent demographic and health surveys show that fuel use is still dominated by charcoal, firewood or organic waste. Where access to this is commercialized – as is the case in many urban centres – total fuel use among low-income residents will be low because of its high cost. If urban households are so constrained in their income levels that families can afford only one meal a day, their consumption will be generating only miniscule amounts of GHGs. Moreover, low-income urban households use transport modes (walking, bicycling or public transportation) with no or low emissions – most of which is used to more than full capacity.[196]

CONCLUDING REMARKS AND LESSONS FOR POLICY

Activities taking place in urban areas – including the actions of individual urban residents – generate a range of GHGs that contribute to climate change. Assessing the contribution of cities to climate change is an important step in developing locally appropriate mitigation actions. The recent launch of a standard methodology that can be used by urban areas around the world to produce comparable data is an important component of this. Yet, as has been shown in this chapter, assessing the contribution of cities to climate change is not a straightforward process, and there has been substantial debate about the proportion of global emissions that can or should be attributed to urban areas. This analysis leads to several key messages: the need for a better understanding of the nature of emissions from cities; the considerable differences in GHG emissions between cities and the wide range of factors contributing to this; the substantial differences in responsibility for GHG emissions from different groups of people within cities; and the importance of examining the underlying drivers of emissions.

There has been an increasing debate about the proportion of global emissions that can or should be attributed to urban areas. This is partially due to the absence of a standardized methodology that has been globally agreed as representing the emissions for which a city is 'responsible'. But it is also compounded by variations in the definition of 'urban areas' between different countries, the ways in which urban boundaries are defined, and the quality of data available. The main sectors for which emissions can be assessed – energy for electricity, transportation, commercial and residential buildings, industry, waste, agriculture, land-use change and forestry – are all relevant to urban areas, which rely on goods, services and processes taking place both inside and outside their boundaries.

There are large differences in GHG emissions between countries and cities around the world, with per capita emissions varying by a factor of 100 or more between the lowest- and highest-emitting countries. There are a variety of factors influencing the total and per capita emissions of a city, including geographic situation (which influences the amount of energy required for heating and lighting), demographic situation (related to both total population and household size), urban form and density (sprawling cities tend to have higher per capita emissions than more compact ones), and the urban economy (the types of activities that take place, and whether these emit large quantities of GHGs).

Most US cities have three to five times the gasoline use per person of most European cities; yet it is difficult to see that Detroit has five times the quality of life of Copenhagen or Amsterdam

However, there are more fundamental underlying factors affecting emissions, primarily related to the wealth and consumption patterns of urban residents. If consumption is taken into account, the emissions from wealthy cities increase substantially, while those from manufacturing cities in developing countries decline. A consumption-based approach has substantial value when considering global emissions reductions – as it removes the incentive simply to 'move' the location of production to countries that are not bound by specific carbon emissions reduction targets. These underlying drivers are inevitably complex, contextually specific, and contingent on a wide range of structural, social, economic and political variables. Reducing urban emissions requires recognizing this complexity and addressing it accordingly.[197]

The importance of cities in directly and indirectly generating GHG emissions indicates that there should be a more central role for sub-national and urban governments in global responses to climate change

In turn, these key findings generate several messages for policy at the global, national and local levels. The importance of cities in directly and indirectly generating GHG emissions indicates that there should be a more central role for sub-national and urban governments in global responses to climate change. Several global networks of cities have been formed with the intention of reducing GHG emissions, sharing knowledge and engaging in advocacy within the UNFCCC. However, there are limited pathways for cities to engage directly in global climate change policy or to receive financing for mitigation activities. Addressing this will require changes in both global and national policy, as national governments will need to recognize the need for cities to act in this arena and provide appropriate legislative frameworks.

A combination of regulations … and incentives … can help to encourage businesses in cities to operate in a way that reduces their contribution to climate change

Addressing the challenge of climate change in cities will require citizens, civil society, the private sector, local and national governments, and international organizations to work together in partnerships

The assessment of the contribution of cities to climate change provided in this chapter also highlights some of the most important areas for responses by city authorities. First, it has been shown that activities undertaken directly by cities can be substantial producers of GHGs. City authorities are often responsible for operating large fleets of vehicles, large numbers of buildings and facilities such as waste disposal sites. These can all produce large amounts of GHGs, yet can also be modified to reduce their contributions.

Second, urban form and the urban economy have been shown to be key factors influencing emissions at the city level. Through their responsibilities for land-use planning and attracting investment, city authorities can help to shape the policy environment within which a range of other stakeholders act. Encouraging relatively dense urban settlements can reduce distances travelled by urban residents and can make public transportation a more appealing prospect. A combination of regulations (e.g. in relation to commercial and industrial energy standards) and incentives (e.g. to support buildings with 'green roofs' or passive solar heating) can help to encourage businesses in cities to operate in a way that reduces their contribution to climate change.

Finally, local levels of government are appropriately positioned to engage directly with citizens to shape behaviour. This chapter shows the importance of individual consumption patterns in contributing to GHG emissions from both within and outside city boundaries. City authorities and civil society can help to generate awareness of the implications of consumption decisions, and can encourage individual urban residents to act in a less carbon-intensive manner. Addressing the challenge of climate change in cities will require citizens, civil society, the private sector, local and national governments, and international organizations to work together in partnerships. Local authorities are located at a crucial nexus for engaging with these different groups and playing a leading role in reducing the contribution of cities to climate change.

NOTES

1 UNFCCC, Article 3. See also Chapter 2.
2 A brief overview of such networks is provided in Chapter 2.
3 UNEP et al, 2010.
4 For a discussion of the characteristics of the main GHGs, see Chapter 1.
5 UNFCCC, 2004.
6 IPCC, 2006.
7 Dodman, 2009.
8 See the section on 'Factors influencing emissions'.
9 WRI/WBCSD, undated. The procedures of this protocol have been adopted by a wide range of private-sector companies (for more details, see www.ghgprotocol.org).
10 Scope 1 emissions represent direct emissions from within a given geographical area; Scope 2 emissions are those associated with electricity, heating and cooling; and Scope 3 emissions include those that are indirect or embodied.
11 See also http://webapps01.un.org/dsd/partnerships/public/partnerships/1670.html.
12 ICLEI, 2008.
13 Fugitive emissions are 'intentional or unintentional release of … [GHGs, which] may occur during the extraction, processing and delivery of fossil fuels to the point of final use' (IPCC, 2006, p4.6).
14 As discussed below in the section on 'The scale of urban emissions'.
15 See note 10.
16 As discussed below in the section on 'The politics of measuring emissions'.
17 These are discussed in more detail below in the section on 'The politics of measuring emissions'.
18 Any new baseline inventory is likely to include aspects of both WRI/WBCSD's Corporate Accounting and Reporting Standard and ICLEI's International Local Government GHG Emissions Analysis Protocol. This will thus take into account the direct emissions from a city, as well as a selected component of cross-boundary emissions included within the WRI/WBCSD concepts of Scope 2 and Scope 3 (Kennedy et al, 2009a).
19 UNEP et al, 2010.
20 Kates et al, 1998.
21 Forstall et al, 2009.
22 Satterthwaite, 2007.
23 Parshall et al, 2009, 2010.
24 These issues are discussed further in the sections below on 'The scale of urban emissions' and 'Factors influencing emissions'.
25 IEA, 2010, p35.
26 IEA, 2010, pp24–25.
27 IPCC, 2007e.
28 Sims et al, 2007.
29 Kennedy et al, 2009b.
30 World Nuclear Association, 2010.
31 Sustainable Energy Africa, 2006.
32 Dhakal, 2009.
33 Sims et al, 2007.
34 Nuclear power plants have very large levels of embedded energy in the building materials and plant construction and decommissioning, as well as in the processing and storing of radioactive waste – much of which comes from fossil fuels.
35 Although this may, in part, be changing now – at least in some countries – in response to the need to reduce the dependence of electricity generation on fossil fuels in light of the increasing concern over climate change.
36 These issues are discussed in more detail in Chapter 5.
37 Sustainable Energy Africa, 2006.
38 Satterthwaite and Sverdlik (2009), citing data from Legros et al (2009).
39 This section draws extensively on Dodman (2009).
40 Barker et al, 2007.
41 Parshall et al, 2009.
42 Romero Lankao et al, 2009a.
43 Ewing et al, 2008.
44 Johnsson-Latham, 2007.
45 Compiled from data presented in Newman (2006) and Dodman (2009).
46 Darido et al, 2009.
47 Compiled from data presented in Newman (2006) and Dodman (2009).
48 Ewing et al, 2008.
49 Ewing et al, 2008.
50 Kutzbach, 2009.
51 Takeuchi et al, 2007.
52 Wright and Fulton, 2005, Figure 1.
53 Wright and Fulton, 2005.
54 Unpublished document, Dar es Salaam City Corporation.
55 WHO, 2004. See also UN-Habitat 2007, Chapter 9.
56 Woodcock et al, 2007.
57 Bloomberg and Aggarwala, 2008.
58 Kahn Ribeiro et al, 2007.
59 Kahn Ribeiro et al, 2007.
60 Kahn Ribeiro et al, 2007.
61 Mayor of London, 2007.
62 City of New York, 2009.
63 Barker et al, 2007.
64 Kennedy et al, 2009b.
65 Parshall et al, 2009.
66 Ewing et al, 2008.
67 Markham, 2009.
68 Gupta and Chandiwala, 2009, p4. The rest of the emissions were from transport (33 per cent), industrial processes (22 per cent) and agriculture (1 per cent).
69 Gupta and Chandiwala, 2009.
70 Yuping, 2009.
71 Sykes, 2009.
72 See www.statcompiler.com, last accessed 12 October 2010.
73 Gupta and Chandiwala, 2009, p11.
74 Gupta and Chandiwala, 2009, p11.
75 This section draws extensively on Dodman, 2009.
76 Bai, 2007
77 Kennedy et al, 2009b.
78 Sustainable Energy Africa, 2006.
79 Dhakal, 2009.
80 Ru et al, 2009.
81 Barker et al, 2007.
82 See Chapter 2.
83 Kennedy et al, 2009b.
84 Dodman, 2009.
85 See below in the section on 'The urban economy'.
86 Hardoy et al, 2001.
87 See section below on 'Factors influencing emissions'.
88 Rogner et al, 2007.
89 UN, undated.
90 Satterthwaite, 2009.
91 Harvey, 1993.
92 VandeWeghe and Kennedy, 2007.
93 That is, including counties such as Arlington and Alexandria which are located in the neighbouring state of Virginia.
94 City of New York, 2009.

95 United States Department of Energy, 2008.
96 City of New York, 2009.
97 City of New York, 2007.
98 City of New York, 2007.
99 City of New York, 2009.
100 City of New York, 2009.
101 Heede, 2006.
102 Brown et al, 2008.
103 Mayor of London, 2007.
104 Baldasano et al, 1999.
105 Gomes et al, 2008.
106 See Table 1.4.
107 The term 'nationally appropriate mitigation actions' was first used in the Bali Action Plan, the main outcome of COP-13, and recognizes that different countries may take different nationally appropriate action on the basis of equity and in accordance with the principle of 'common but differentiated responsibilities and respective capabilities' (see Chapter 2).
108 Patricia Romero Lankao, pers comm., 2009.
109 Sustainable Energy Africa, 2006, p83.
110 PADECO, 2009a.
111 Ananthapadmanabhan et al, 2007. The two categories refer to the 10 million people (1 per cent of the population) in India who earn more than 30,000 rupees (approximately US$700) per month, and the 432 million people (38 per cent of the population) who earn less than 3000 rupees (approximately US$23) per month.
112 Satterthwaite, 2009.
113 PADECO, 2009b.
114 Wang and Huang, 1999.
115 Roy, 2009.
116 Satterthwaite, 2008a.
117 Walraven, 2009.
118 OECD, 1995.
119 Walraven, 2009.
120 See the section on 'The politics of measuring emissions'.
121 See the section on 'The sources of greenhouse gas emissions'.
122 Valor et al, 2001.
123 Glaeser and Kahn, 2008.
124 Energy Information Administration, undated.
125 REN21, 2009.
126 Romero Lankao et al, 2009a.
127 Dalton et al, 2008.
128 Jiang and Hardee, 2009.
129 Martine, 2009.
130 Newman, 2006.
131 This section draws significantly on Dodman, 2009.
132 Gottdiener and Budd, 2005.
133 McGregor et al, 2006.
134 Angel et al, 2005.
135 Rabinovitch, 1992.
136 UNFPA, 2007.
137 Angel et al, 2005.
138 Brown et al, 2008, pp11–12.
139 Newman and Kenworthy, 1999.
140 Brown et al, 2008, p12.
141 Satterthwaite, 1999.
142 Gottdiener and Budd, 2005.
143 Newman and Kenworthy, 1989.
144 Brown and Southworth, 2008.
145 VandeWeghe and Kennedy, 2007.
146 Norman et al, 2006.
147 'The "urban heat island" effect is caused by day time heat being retained by the fabric of the buildings and by a reduction in cooling vegetation... In tropical cities, the mean monthly urban heat island intensities can reach 10°C by the end of the night, especially during the dry season' (Kovats and Akhtar, 2008, p165).
148 Ewing et al, 2008.
149 Mayor of London, 2007.
150 Coutts et al, 2008.
151 Campbell-Lendrum and Corvalan, 2007.
152 The impacts of climate change on cities are discussed further in Chapter 4.
153 Neuman, 2005.
154 Jabareen, 2006.
155 Andrews, 2008.
156 Burdett et al, 2005, p4.
157 Bertaud et al, 2009.
158 Bertaud et al, 2009, p29. At least two reasons help to explain this: companies do not hire based upon who lives within their business areas, and economic realities prevent people from restricting their job searches to only those businesses that are within walking or biking distances from their homes.
159 Mayor of London, 2007.
160 See the section on 'Industry' above.
161 Weber et al, 2008.
162 Walker and King, 2008.
163 Compiled from data presented in Newman (2006) and Dodman (2009).
164 See note 10.
165 Dhakal, 2008.
166 VandeWeghe and Kennedy, 2007.
167 Referred to as 'Annex I countries' in the Kyoto Protocol.
168 See Chapter 2.
169 See note 110.
170 Referred to as 'non-Annex I countries' in the Kyoto Protocol.
171 As seen in the case of São Paulo, Brazil (see Box 3.3; and Dubeux and La Rovere, 2010).
172 This is discussed in more detail in Chapter 5.
173 Rees, 1992; Rees and Wackernagel, 1998; Wackernagel et al, 2006; Girardet, 1998.
174 Rees, 1992, p121.
175 Hertwich and Peters, 2009.
176 Hertwich and Peters, 2009.
177 Dhakal, 2004.
178 Bai, 2007, p2.
179 Bastianoni et al, 2004.
180 Peters, 2008.
181 Satterthwaite, 1997b.
182 Halweil, 2002; Murray, 2005.
183 Hendrickson, undated.
184 Garside et al, 2007.
185 Peters, 2008.
186 Adger, 2001.
187 Terry, 2009.
188 Johnsson-Latham, 2007.
189 See the section on 'The scale of urban emissions'.
190 Dhakal, 2008.
191 Women's Environment Network, 2010.
192 Patt et al, 2009. See also Chapters 4 and 6.
193 Dhakal, 2008.
194 Newman, 2006.
195 Satterthwaite, 2008a.
196 Satterthwaite, 2009.
197 See Chapter 5.