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Chapter 12

Human Settlements, Infrastructure and Spatial Planning

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This chapter has been allocated 52 template pages, currently it counts 55 pages (excluding this page and the bibliography), so it is 3 pages over target. Reviewers are kindly asked to indicate where the chapter could be shortened.

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Chapter 12: Human Settlements, Infrastructure, and Spatial Planning

Contents

Executive Summary

Human settlements are dominated by seven trends: urbanization, expansive land-use change, declining population densities, declining built-up densities, the emergence of very large settlements, the unprecedented physical scale of individual settlements, and a geographic shift to developing countries, where nearly all future population growth will occur (*robust evidence, high agreement*). These trends in where and how humanity lives are paralleled with the economic growth and the transition from traditional to modern energy sources. Between 2009 and 2050, urban areas are projected to absorb the entire world's population growth while the rural population will begin to decline around 2020. By 2050, urban population is projected to increase to 6.3 billion from 3.4 billion in 2009. Urban population growth will be concentrated in Asia (1.7 billion) and Africa (0.8 billion). The fraction of anthropogenic GHG emissions from human settlements depends on the definition of urban areas and the emissions accounting methods (*robust evidence, high agreement*).

The future growth in material stocks will occur primarily in developing countries (*high confidence*), but there is no consensus as to how much infrastructure stock will be required. In 2008, the built-up infrastructure globally embodied between 102 and 137 Gt CO2-eq, with between 55 and 78 Gt CO2-eq in Annex I countries and between 47 and 59 Gt CO2-eq in non-Annex I countries. The existing infrastructure of the average Annex I resident is three times that of the world average and about five times higher than that of the average non-Annex I resident (*limited evidence*).

Direct emissions associated with human settlements account for 75-81% of global CO_2 emissions from 1990 to 2008 (*limited evidence, high agreement*). Areas with urban populations are responsible for 29.9 to 35.7% of global CO_2 emissions from 1990 to 2008, and for 4.7 (56%) of 8.3 Gt increase in emissions over that period. The share of emissions from rural areas has not increased, remaining in the range 43.2 to 45.5%. An increase of 3.8 Gt (46%) is attributed to direct emissions in areas with rural populations, while other emissions have decreased 0.2 Gt (-2%) due primarily to variability in large-scale biomass burning. Urban areas are responsible for the dominant share of carbon dioxide emissions from waste management (82%), and the combination of materials production and manufacturing (85%), while rural areas have the dominant shares of CO_2 emissions from use-phase activities (51%) and energy production (65%). However, there is no strong agreement on these estimates and different methods have yielded different figures.

There is large variation in urban emissions across countries and regions. African urban GHG emissions are approximately 21-30% of total African CO_2-eq. emissions. In contrast, North American urban CO_2-eq. emissions are estimated to be 49-73% of total North American emissions. Amongst developing countries, urban CO_2-eq. emissions range from approximately 26-33% of total emissions. Among developed countries, urban CO_2-eq. emissions range from approximately 47-63% of total (*limited evidence, high agreement*).

There is *robust evidence and high agreement* that urban form, design, and connectivity are important in shaping the levels of urban GHG emissions. Urban form is responsible directly for a large proportion of consumed energy and indirectly influences the choice, patterns and modes of energy consumed in everyday activities. Human settlements could meet low carbon targets through two primary whole-system approaches: spatial planning and metabolism. There is *robust evidence* that low carbon human settlements have the following characteristics: (1) high population and employment densities that are co-located; (2) compact urban form; (3) mixed land uses; (4) high connectivity; (5) destination accessibility; and (6) integrated multi-transport modes. Furthermore, there is *robust evidence* that planning strategies as growth management, public transit investments, transit-oriented development, integrated transportation planning, and land value capture can achieve the above characteristics. However, there is little consensus on the optimal set of strategies that could effectiveness reduce GHG emissions or the exact magnitude of the effect.

There is *robust evidence* that governance of land use and planning is not solely dependent on municipal authorities and that there are significant challenges to overcoming existing governance and institutional barriers to achieve low carbon development. There is *high agreement* that multi-level governance and institutional arrangements are required to move human settlements towards the principles of low carbon development.

Since the IPCC 4th Assessment Report, thousands of cities around the world have implemented or are developing local climate change mitigation plans. Although municipal governments and civil society are taking leadership to reduce carbon emissions at the local level, there are few evaluations of the effectiveness of these urban climate action plans and their implementation has been slow.

12.1 Introduction

The Vancouver Declaration on Human Settlements defines human settlements as the totality of the human community whether city, town, or village, with all the social, material, organizational, spiritual, and cultural elements that sustain it (United Nations, 1976). The fabric of human settlements consists of physical elements and services to which these elements provide the material support. The physical components comprise shelter, infrastructure (e.g., the complex networks designed to deliver to or remove from the shelter people, goods, energy, or information) and services (to support the communities' functions as a social body, such as education, health, culture, welfare, recreation and nutrition). Over the years, the concept of human settlements has been broadened to become a framework for an overall national socio-economic development. Human settlements now include both the spatial dimension as well as the physical expression of economic and social activity (UN ESCAP, 2013). If defined so broadly, global human settlements and their infrastructures account for all anthropogenic GHG emissions: human settlements sustain their functions through an increasingly global socio-economic metabolism that includes all sectors.

In this chapter, infrastructures are broadly defined as those services and built-up structures that provide water, energy, food, shelter (construction materials), mobility/connectivity, sanitation, waste management and public amenities (Ramaswami, 2013). Essential infrastructures often transcend city boundaries and hence are termed "transboundary" (Ramaswami et al., 2012). For example, the energy used to provide key infrastructure services such as electricity, transport fuels, or freight transport often occurs outside the boundaries of the cities using them. Human settlements can reduce greenhouse gas emissions through two principle strategies: through individual component sectors or the constituent of a settlement as a whole. Chapters 7, 8, 9, and 10 describe the mitigation options for component sectors related to human settlements: energy systems, transport, buildings, and industry, respectively. This chapter addresses options for reducing greenhouse gas emissions for a human settlement as a functional unit, with a focus on urban settlements, infrastructure, and spatial planning.

This chapter focuses on urban settlements for four reasons. First, between 60-80 percent of final energy use globally occurs in urban areas (GEA, 2012). Second, urban areas are economic centers and generate more than 90% of global gross value added (United Nations, 2011a). Third, the majority of the future increase in population will occur almost entirely in urban areas (United Nations, 2011b). Between 2009 and 2050, urban areas are projected to absorb the entire world's population growth while the rural population will begin to decline. By 2050, urban population is projected to increase to 6.3 billion, from 3.4 billion in 2009, concentrated in Asia (1.7 billion) and Africa (0.8 billion). Fourth, the increase in urban populations will be accompanied by unparalleled levels of new construction of built environments and infrastructure, requiring significant energy and natural resources. Given such trends, it is clear that urban settlements are and will be increasingly central to climate change.

Although urban settlements make up much of global energy use, economic production, and population, there is no consensus on the definition of urban. Rather, there is significant variation between country-defined definitions, with some defining urban as a settlement with a combination of minimum population size of between 2000 and 5000 inhabitants, an economy that is primarily non-agricultural, and the presence of infrastructure (United Nations, 2011b). In this chapter, "urban" describes a human settlement with any of the following characteristics: 1) a minimum population size as defined by an individual country; 2) an economic base that is largely non-agricultural; 3) a concentration of economic resources, the built environment and infrastructure; and 4) having some legal authority or governance over a geographic region (Figure 12.1).

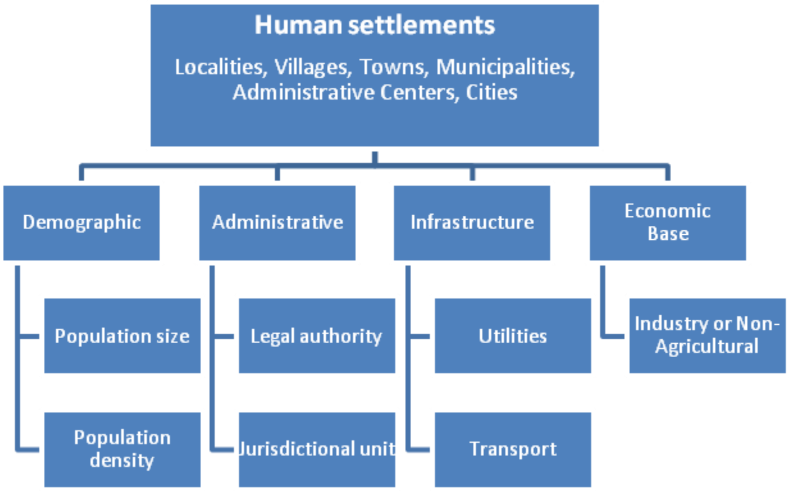


Figure 12.1. Characteristics and types of human settlements

12.2 Human settlements and GHG emissions

12.2.1 Trends in human settlements

There are four primary trends in human settlements today. First is that that more people live in urban settlements than rural settlements. More than half of the world population lives in urban areas. Second, the population of individual urban areas is larger than any other time in history. Mumbai, Lagos, and Tokyo each have populations of over 20 million. In contrast, Beijing was the only city with 1 million people in 1800. Third, about 60% of the global urban population live in relatively small cities, those with fewer than one million people. Less than 10% global urban population lives in megacities, defined as cities with populations of 10 million or greater (Figure 12.2).

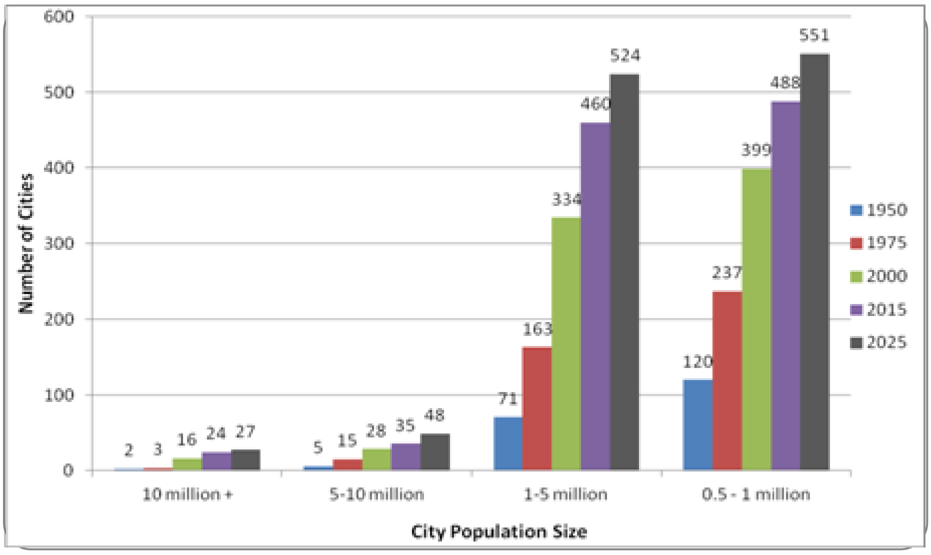


Figure 12.2. Number of cities by size, source: United Nations, 2011b.

Fourth, urban growth in the coming decades will take place primarily in Asia and Asia (Figure 12.3). Urban settlements also exhibit geographic variations in scale, distribution, and patterns of the growth.

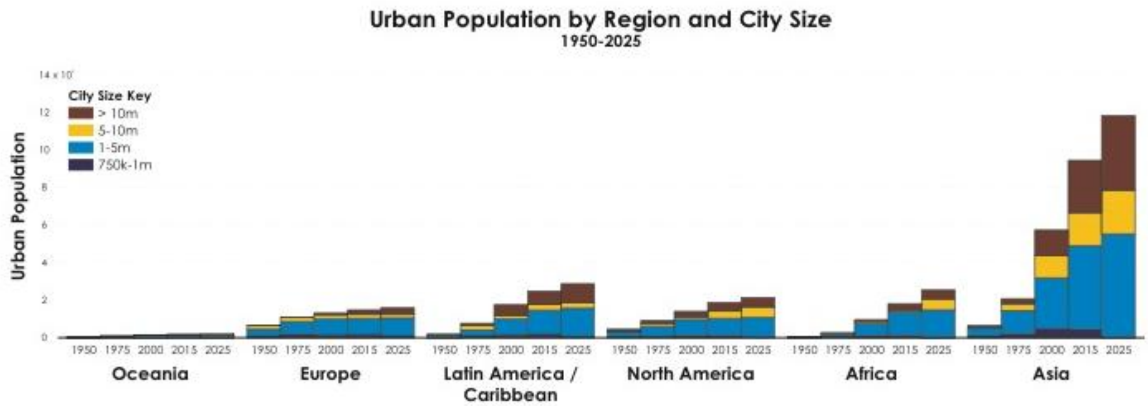


Figure 12.3. Urban population by region and city size, source:United Nations, 2011b.

12.2.2 Trends in urban land use

Urban areas have historically been spatially compact with concentrated populations. Urban areas are now increasingly expansive and characterized by low-density fragmented development. Individual case studies show that urban areas have reached physical sizes that are unmatched in history. The urban extent of Tokyo-Yokohama is more than 13,500 km^2, an area that is bigger than Jamaica (11,000 km^2). Between 1970 and 2000, more than 58,000 km^2, an area approximately 1.3 times the size of Denmark, were converted to urban uses worldwide (Seto et al., 2011) and it is highly likely that more than 1.2 million km^2, an area nearly equal to South Africa, will become urban by 2030 (Seto et al., 2012).

12.2.3 Trends in urban population densities

Worldwide, across all income levels and city sizes, urban population densities are declining. On average, urban population densities are four times higher in low income countries (11,850 persons/km^2 2000) than in high income countries (2,855 persons/km^2 in 2000). Urban population densities are highest in South (13,720 persons/km^2) and Southeast (16,495 persons/km^2) Asia although they have also declined from 1990 levels (Table 12.1) (World Bank, 2005).

Table 12.1: Average density and built up area per person across regions, income group and city size groups, 1990-2000, source: (Angel et al., 2005)

Category	Average Built-up Area Density			Average Built-up Area per Person		
	1990	2000	Annual % Change	1990	2000	Annual % Change
Developing Countries	9,560	8,050	-1.7%	105	125	1.7%
Industrialized Countries	3,545	2,835	-2.2%	280	355	2.3%
Region						
East Asia & the Pacific	15,380	9,350	-4.9%	65	105	5.1%
Europe	5,270	4,345	-1.9%	190	230	1.9%
Latin America & the Caribbean	6,955	6,785	-0.3%	145	145	0.3%
Northern Africa	10,010	9,250	-0.8%	100	110	0.8%
Other Developed Countries	2,790	2,300	-1.9%	360	435	2.0%
South & Central Asia	17,980	13,720	-2.7%	55	75	2.7%
Southeast Asia	25,360	16,495	-4.2%	40	60	4.4%
Sub-Saharan Africa	9,470	6,630	-3.5%	105	150	3.6%
Western Asia	6,410	5,820	-1.0%	155	170	1.0%
Income Category						
Low Income	15,340	11,850	-2.5%	65	85	2.6%
Lower-Middle Income	12,245	8,820	-3.2%	80	115	3.3%
Upper-Middle Income	6,370	5,930	-0.7%	155	170	0.7%
High Income	3,565	2,855	-2.2%	280	350	2.2%
City Population Size						
100,000 - 528,000	5,955	4,810	-2.1%	170	210	2.2%
528,000 - 1,490,000	7,620	5,970	-2.4%	130	165	2.5%
1,490,000 - 4,180,000	6,870	6,040	-1.3%	145	165	1.3%
More than 4,180,000	5,860	5,405	-0.8%	170	185	0.8%
Global Average	6,485	5,470	-1.7%	155	185	1.7%

Note: Based on weighted averages of the 90-city sample.

12.2.4 Trends in urban built-up densities

Worldwide, the rate of urban expansion exceeds the rate of urban population growth, and across all income levels and city sizes, the amount of built-up area per person is increasing (Seto, Sánchez-Rodríguez, et al., 2010; Angel et al., 2011). Urban areas in Asia experienced the largest decline in population densities during the 1990s (Table 12.1). In East Asia, urban population densities declined 4.9%, from 15,380 persons/km^2 in 1990 to 9,350 persons/km^2 in 2000. In Southeast Asia , urban population densities declined 4.2%, from 25,360 persons/km^2 in 1990 to 16,495 persons/km^2 in 2000. These figures are still higher than urban population densities in Europe, North America, and Australia, where densities are on average 2,835 persons/km^2. As the urban transition continues in Asia and Africa, it is expected that urban densities there will also continue to decline.

12.2.5 Trends in urban development and infrastructure

Human settlements and infrastructure development patterns define the boundary conditions for mitigation efforts over several decades in multiple ways: (i) the long lifetime of built environment structures limit the speed at which emissions in the use phase (e.g., buildings and transport) can be reduced (Table 12.2); (ii) their build-up requires large amounts of primary resources that contribute to industry emissions; and (iii) once these structures have reached the end of their lifetime, the materials they embody may be recovered for reuse or recycling ("urban mining"), which not only saves primary resources and waste, but often also large amounts of energy and emissions in industry and energy supply.

The growth phase of built environment stocks (e.g., during early stages of urbanization when infrastructure development is relatively high) is therefore particularly energy and emission intensive. For example, China, which is experiencing high rates of urbanization, accounted for about 46% of global steel production and for about 54% of the global cement production in 2009 (U.S. Geological Survey, 2011). There is evidence that the rapid CO_2 emission increase in China between 2002 and 2007 was caused by a change in China's economic structure towards carbon intensive activities (such as cement and steel production) associated with the supply chain of the construction industry (Minx et al., 2011). Growth patterns of built environment stocks are therefore important factors defining boundary conditions for emission pathways (Liu et al., 2012). Vehicle ownership tends to flatten in industrialized countries although no saturation level can be observed yet (Pauliuk et al., 2011). Floor area of residential buildings is still expanding even in high income countries, yet often with a declined growth rate (Müller, 2006; Bergsdal et al., 2007). Therefore, the dominant trend is continued increase in infrastructure development across the world.

Table 12.2: Lifespan of infrastructure components, source: Schiller, 2007.

Roads				Drinking water		Sewage	
Component	Lifespan (roadway) (years) Upper layer	Lifespan (roadway) (years) Base layer	Lifespan (pavement) (years)	Component	Lifespan (years)	Component	Lifespan (years)
Concrete road	20	50	55	Steel pipeline	75	Stone pipeline	120
Bitumen road	15	50	60	Cast-iron pipeline	100	Concrete pipeline	90
Paved road	35	45	55	Cast-iron pipeline with inlay	110	Fibre-cement pipeline	65
Unsurfaced road	5	30	25	Plastic pipeline	75	Plastic pipeline	75

12.2.6 Trends in urban energy use and emissions

While nearly all future population growth occuring in urban areas in non-OECD countries, this will be paralleled with the transition from traditional to modern energy sources. Patterns of urban energy use exhibit significant variation between and within countries. In OECD countries, per capita energy use in urban areas is generally lower than national averages. In contrast, in developing countries, per capita energy use in urban areas is generally higher than national averages. In developing countries, higher per capita energy use in urban areas is due to the quantity and type of energy use for home-based activities, transportation, production, and consumption.

One important trend in some urban areas is the transition from a large industrial base to services, including parallel changes in energy portfolio and concomitant declines in per capita urban emissions. For example, per capita emissions in Beijing are expected to decline from 7.67 tCO2 in 2005 to 6.00 tCO2 in 2030 largely as a function of changes in economic structure (Feng et al., In press).

Urbanization and rising incomes are usually accompanied with switches to cleaner and more convenient fuels for cooking and an increase in electricity access. In India, the switch is from biomass to kerosene to LPG to electricity (Farsi et al., 2007; Mestl and Eskeland, 2009). Key factors in fuel switching in developing countries include household education level, electrification, household size, household expenditures (Viswanathan and Kavi Kumar, 2005; Mestl and Eskeland, 2009). In Africa, the electrification rate is 41.8% and 587 million people—57% of the population— are without access to electricity (IEA, 2011). In Asia, there are countries with significant portions of the population lack access to electricity. For example, 81.6 million people in Indonesia—one third of the country—are without electricity. In India, 25% of the population do not have access to electricity.

For urban populations in India, larger changes in fuel use mix are forecasted. At the same time, per capita fuel consumption are forecasted to double. Under business as usual scenarios, India's per capita household GHG emissions are expected to increase by 169% by 2030 over 2001 levels (Mestl and Eskeland, 2009). There is significant variation in residential energy use between urban and rural areas and between high and low income groups. In India, residential final energy use is forecasted to increase 65-75% between 2005 and 2050, with carbon emissions from fossil fuels expected to increase 9-10 times during this period (Van Ruijven et al., 2011).

FAQ 12.1 Why is the IPCC including a new chapter on human settlements and spatial planning? Isn't this covered in the individual sectoral chapters?

More than 50% of the world population lives in urban areas now and by 2050, close to 70% will live in urban areas. Because of the scale of urban populations, urban expansion and the contribution of urban areas to global emissions, it is important to assess how human settlements can mitigate climate change using a systemic or holistic perspective. Taking a settlements perspective allows for optimizing the system rather than its individual components.

12.3 Urban systems: activities, resources, and performance

12.3.1 Role of human settlements and infrastructure for GHG emissions

Globally, direct anthropogenic CO2 emissions originate from energy supply (38% in 2008), followed by industry (20%, with materials production accounting for 16% cement alone contributing>10%) transport (18%), agriculture, forestry, and land use change (16%), buildings (8%), and waste management (0.1%)(Figure 12.4) (Müller et al., 2013).

The fraction of these sectors that can be assigned to human settlements depends on the definition of human settlements. Several studies show that the transboundary emissions of infrastructure provision can be as large or sometimes larger than the direct GHG emissions within city boundaries (Chavez and Ramaswami, In Press; Ramaswami et al., 2008a; Kennedy, Steinberger, et al., 2009a; Hillman and Ramaswami, 2010a). Transboundary emissions include a number of different components called by different terms: a) sector emissions that inherently extend beyond the city boundary such airline, freight or commuter travel; b) indirect energy use in the context of electricity such as primary energy used at power plants to generate electricity; and c) embodied energy of various materials referring to the upstream energy used to produce these materials. A full life cycle assessment of energy use and GHG emissions of infrastructure would include both indirect energy as well as embodied energy of materials in that infrastructure, plus use-phase emissions such as fuel combustion in homes or vehicles. The portion of life cycle GHG emissions that occur outside the boundary of the city where the infrastructure is used is termed “transboundary”.

National accounts give us a picture of the extent to which all economic activity sectors together contribute toward GHG emissions; these can then be mapped to infrastructure sectors (energy, transportation. food production, etc.) as shown in Table 12.3. For the US, these sectors together are estimated to contribute more than 99% of total GHG emissions without allocating to urban or rural areas (Table 12.3). National accounts also allow us to assess as the percent contribution by each sector. For example, we know that freight contributes about 7.8% of GHG emissions in the US totally and this sector may then be allocated to rural and urban areas in different ways.

Table 12.3 U.S. National-Scale GHG Emissions by End-Use Economic Activity Sectors (Hillman and Ramaswami, 2010a)

TABLE 1. U.S. National-Scale GHG Emissions by End-Use Economic Activity Sectors Are Mapped to City-Scale Scope 1, Scope 2, and Scope 3 Activity Sectors[a,b]

U.S. national GHG emissions by economic activity sectors[b] (% contribution)	Related city-scale activities and scopes	
Residential and commercial energy use and related GHG emissions (33.9%)	Residential and commercial energy use within city boundaries and related GHG emissions [Scope 1 (i.e., direct fossil fuel combustion) + Scope 2 (i.e., electricity generation)]	In-boundary buildings/ facilities GHG emissions
Industrial energy use and GHG emissions (28.7%)	Industrial energy use and GHG emissions within city boundaries; larger cities have a balance between industrial-commercial-residential activities [Scope 1 + Scope 2]	In-boundary buildings/ facilities GHG emissions
	Industrial energy use and GHG emissions if occurring outside city boundaries to meet critical urban materials demand: cement production, petro-fuel production, water/wastewater/ waste treatment, etc.[Scope 3]	
Personal road transport (17.8%)	Petro-fuel use for personal transport within regional commutershed, allocated to individual cities based on travel demand [Scope 1]	In-boundary surface transport emissions
Freight transport (7.6%)	Petro-fuel use for commercial trucks within regional commutershed, allocated to individual cities based on travel demand [Scope 1] **Long distance freight trucking outside region[c] [Scope 3]**	In-boundary surface transport emissions
Airline transport (2.3%)	**Jet fuel use for airline travel from regional airport, allocated to individual cities using that airport [Scope 3]**	
Agriculture (8.5%)	**Emissions from food production (excluding freight) to meet food consumption demand in cities [Scope 3]**	
Total: 99% of national GHG emissions[c]	Total: with scope 1+2+3 inclusions, city-scale GHG accounts should include in-boundary and key cross-boundary activities, appropriate for a GHG footprint computation.	

[a] Six Scope 3 items related to cross boundary transport (airline and freight) and embodied energy of materials are shown in bold. [b] National GHG emissions by economic activity sectors from U.S. EPA (*11*); emissions only (no sinks). [c] Excludes 0.9% contributed by U.S. Territories (*11*). [d] Long-distance rail transport is not included as economic census data is not reported for this sector, and rail contributes less than 0.7% of national GHG emissions.

12.3.1.1 Direct in-boundary emissions from a socio-metabolic systems perspective

In contrast to a global perspective of human settlements, individual human settlements are open systems with porous boundaries. Their direct emissions—those associated with GHG emission sources within the boundary—may vary substantially depending on a variety of factors, such as economic activities within the community (including trade), lifestyle, technology, and infrastructure stock development. Due to the porosity of human settlements, their direct or territorial emissions are often a poor indicator for their inhabitants' responsibility to global anthropogenic emissions. In addition, direct emissions accounting alone does not reveal the entire potential for these communities to contribute to global emissions cuts (see 12.3.2). Due to the socio-metabolic linkages between the sectors within and outside communities, interventions for reducing emissions in one sector usually have implications not only for this sector, but also for the socio-metabolic system, with consequences for emissions in other sectors within or outside the system boundaries (see 12.3.5). A systems perspective can help decision makers to anticipate secondary effects on greenhouse gas emissions and other environmental issues, such as resource depletion and other emissions.

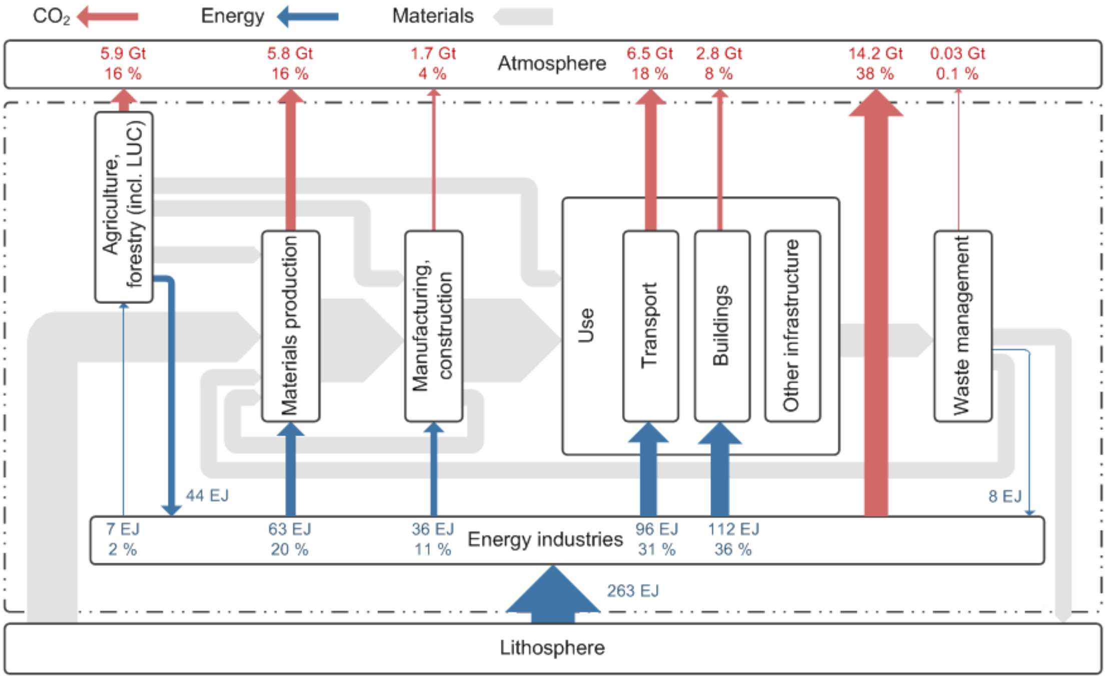


Figure 12.4. Global anthropogenic metabolism for material (grey), energy (blue) and CO2 emission flows (red) in 2008, excluding assimilation and short-cycle emissions from biomass, and water (Müller et al., 2013). LUC: Land use change; Manufacturing includes food industry. CO_2 data are based on the Emissions Database for Global Atmospheric Research (Ramaswami et al., 2008a)(EDGAR, version 4.2) (European Commission and Joint Research Centre/Netherlands Environmental Assessment Agency, 2011). Energy data are compiled from the International Energy Agency (IEA) (International Energy Agency, 2008, 2010, 2012). Material data are not quantified.

12.3.2 Urban energy and emissions accounting

12.3.2.1 City- versus national- GHG accounting: challenges of spatial scale and boundary

There is wide recognition that strict territorial source-based accounting of GHGs employed at the national scale is, by itself, not meaningful for the smaller spatial scale of cities which typically span a few tens to a hundred miles across, and are often much smaller than nations. The smaller spatial scale of cities compared to nations gives rise to two challenges.

First, cities are often typically smaller than the larger scaled infrastructures in which they are embedded, so cities can have large transboundary emissions from infrastructures such as electricity grids, fuel supply chains, food supply chains, and commuter, freight and airline networks. See Figure 12.5 where the transboundary infrastructure contributions are shown as hatched for Denver (1a) and Delhi (1b).

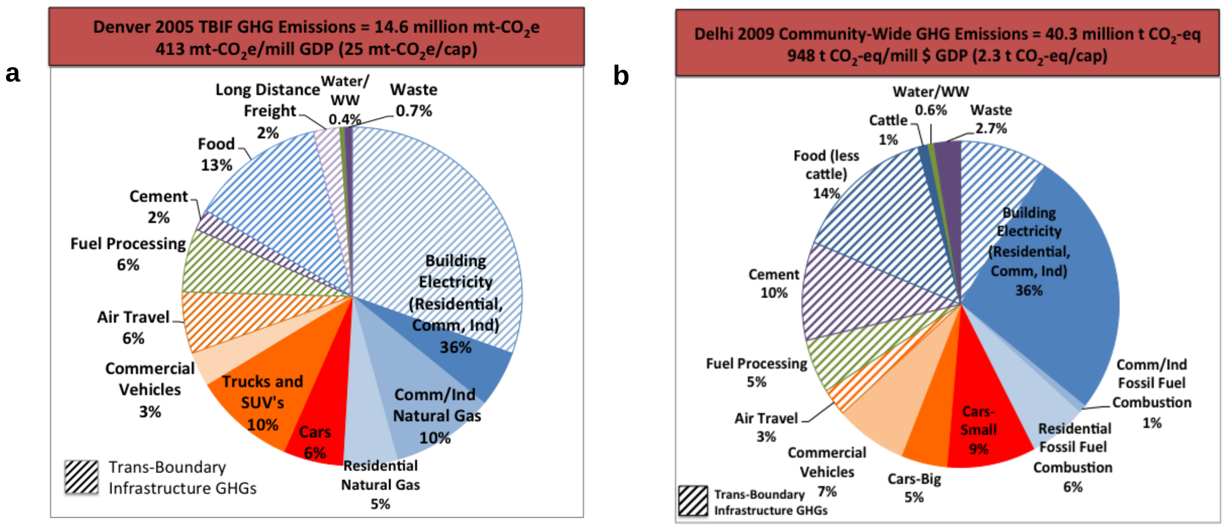


Figure 12.5. Community-Wide Infrastructure Supply Chain Greenhouse Gas (GHG) Emission Footprints for a) Denver, US and b) Delhi, India. Transboundary contributions are hatched, including the percent of electricity imported (adapted from (Ramaswami et al., 2008b; Chavez et al., 2012)**.**

Second, beyond infrastructures, there is also trade of other non-infrastructure goods and services across cities, such as furniture and clothing that may be used in one city but are produced elsewhere, using energy and emitting GHG emissions at the different locations along the supply chain associated with the production process.

<u>Activity-Based Accounting for Cities</u>

Thus, human activity in cities that occur in residential, commercial and industrial sectors stimulates both in-boundary GHG emissions as well as trans-boundary emissions as shown in Figure 12.6. shows a generalized schematic that illustrates in-boundary energy-use as well as trans-boundary energy flows associated with homes, businesses and industries co-located within a city (Chavez and Ramaswami, In Press).

There is now a consensus among both the scientific and the practitioner communities that GHG accounting for individual cities must link human activities in cities with GHG emission sources irrespective of the location of these sources (Ramaswami et al., 2011). It is often useful to delineate the location of the GHG emission-sources associated with each activity as: Scope 1 (Direct or In-boundary GHG Emissions); Scope 2 (Indirect energy associated with electricity imported to the city), and, Scope 3 (other transboundary and life cycle emissions). By including a consistent set of activities and subsequently linking them to sources, GHG accounting can be consistent applied for all cities irrespective of their spatial scale or boundary.

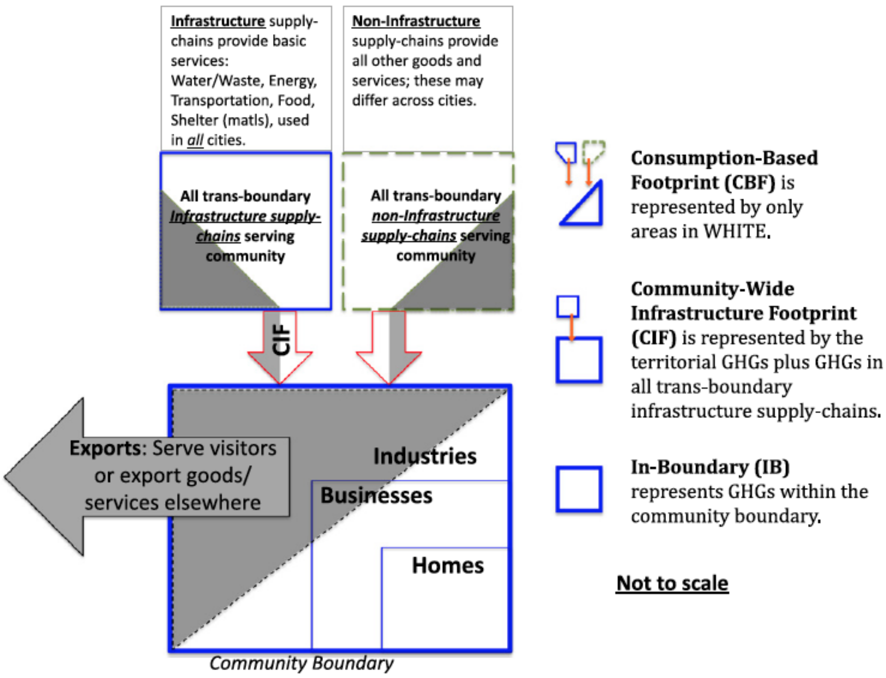


Figure 12.6. Schematic illustrating the distinction between in-boundary GHGs, community wide infrastructure GHG footprints (CIF) and consumption-based GHG footprints (CBF) (Chavez and Ramaswami, In Press).

12.3.2.2 Three approaches to GHG accounting for individual cities

Based on the rationale presented above, three broad approaches for GHG accounting at the city-scale have emerged, the first focused on in-boundary GHG emission sources, and the latter two focused more on activities and their subsequent linkage to sources (Chavez and Ramaswami, In Press; Ramaswami and Chavez, 2013).

Purely In-Boundary Source-based GHG Accounting (IB)

In-boundary accounts mirror the national accounting methods by inventorying all direct fuel combustion and GHG emission sources from homes, businesses and industries co-located within a city's boundary. All direct emissions from these sectors are included in the in-boundary GHG emissions account, e.g., fuel combustion to heat homes, gasoline combustion in vehicles, industrial energy use (including for power generation) and non-energy process emissions. Purely territorial accounting within a city is useful because this provides the basic GHG source data that are then allocated to cities based on activity-data in the subsequent two methods. Furthermore, purely territorial source-based accounting provides a good measure of local pollution arising from fuel combustion (SOx, NOx, PM). However, unlike in national accounts, the in-boundary focus does not effectively reflect human activities within the boundary—neither production nor consumption—because of the artificial truncation of several key infrastructures serving cities, in particular the electricity grid, energy supply networks and transportation networks.

Community-Wide Infrastructure GHG Footprints (CIF)

The transboundary community-wide infrastructure footprint (CIF) links infrastructure-use stimulated by human activities within the city with the production of these infrastructure services, irrespective of where they are produced. CIF reports life cycle GHG emissions associated with community-wide use of a finite set of key infrastructures that provide energy, water, food, mobility/connectivity, construction materials, sanitation, waste management and public spaces to the entire community consisting of homes, businesses and industries co-located in the city (Chavez and Ramaswami, In Press; Ramaswami, 2013). These infrastructures are essential for basic life functions, and/or are also highly correlated with economic development in all cities while being produced in only a few cities.

From a policy perspective, the CIF is relevant to future infrastructure planning. Because multiple infrastructure sectors (buildings energy, transportation, water supply etc.) are considered together (See Figure 12.5), CIF enables analysis of cross-infrastructure substitutions, such as substituting airline travel in the transportation sector with more energy-efficient teleconferencing which lies in the buildings sector, saving energy by saving on water supply (the water-energy nexus), and utilizing food and other wastes to generate energy. Most importantly, the method prevents shifting of GHG emissions “outside” as society transitions to new fuel infrastructures like hydrogen that have zero tailpipe emissions within the city.

Consumption-Based Footprints (CBF)

CBFs compute life cycle (in-boundary and trans-boundary GHGs) associated with the consumption of both infrastructure and non-infrastructure goods and services by a sub-set of a community – its final economic consumption sector, typically dominated by local households. However, energy use by visitors to the local community, as well as by businesses and industries that serve those visitors or that export goods and services elsewhere, and their supply chains are excluded from the CBF of that community. CBF is therefore primarily useful to inform local resident households of the global GHG impact of the full suite of goods and services they consume.

The differences in accounting methods are evident when mathematically derived for three types of cities: net-producing, net-consuming, and trade-balanced (Figure 12.7). The comparison reveals that neither CIF nor CBF is shown to be automatically “more holistic” in and of themselves. Both are complementary, they measure different although overlapping flows, and they inform different GHG mitigation strategies. Most importantly, Figure 12.7 cautions against comparing cities solely on a per capita GHG emissions. In summary, the CBF is more useful to inform and shape consumer behavior, while the CIF addresses community-wide energy use and infrastructure planning; IB informs local pollution.

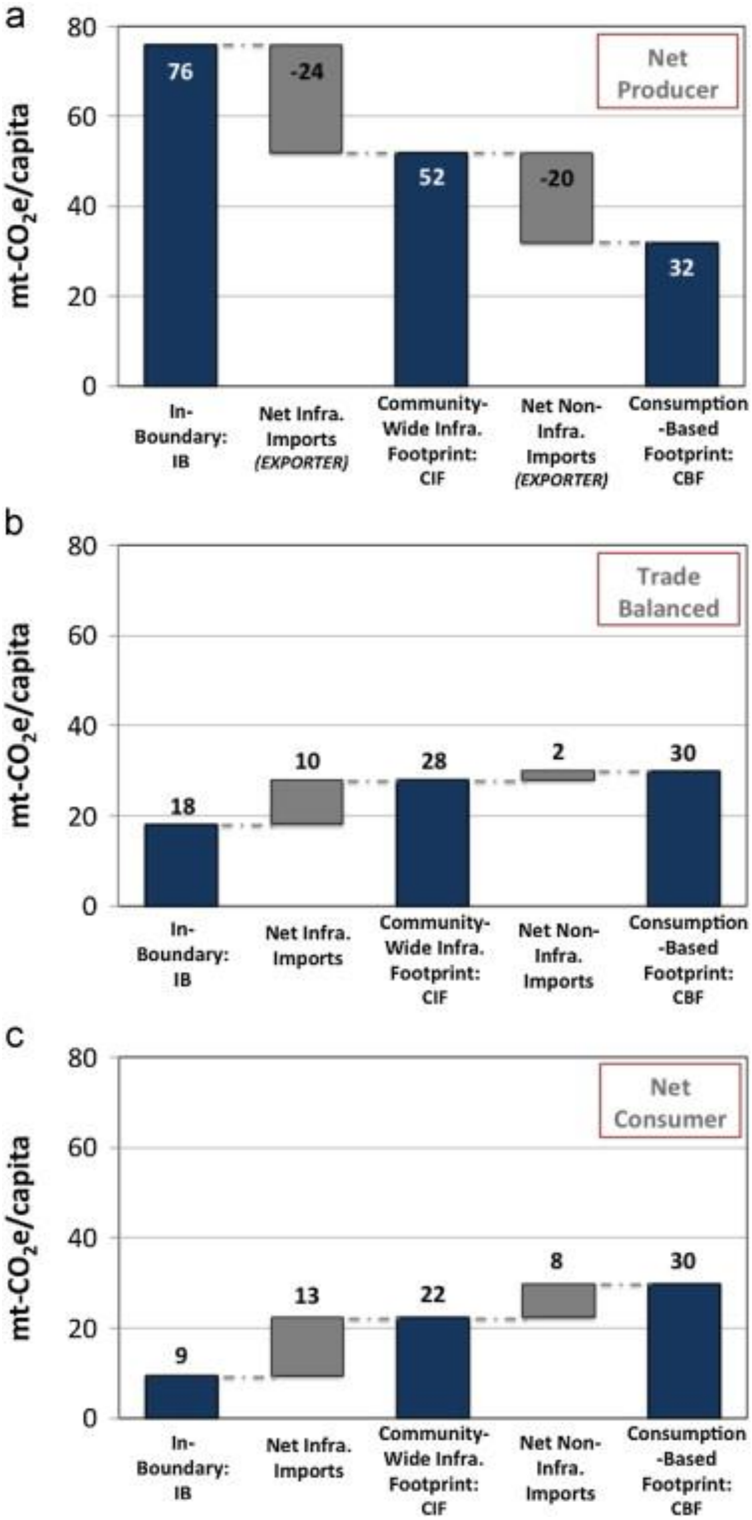


Figure 12.7. Relationship between In-boundary (IB), trans-boundary Community-wide Infrastructure Footprint (CIF) and Consumption-based Footprints for three different city types: Net producers, net-consumers, and trade-balanced. Source: (Chavez and Ramaswami, In Press).

12.3.2.3 Observations about infrastructure sector contributions

To date, community-wide infrastructure supply chain footprints (CIFs) have been computed for more than 80 cities (Table 12.4). Not all infrastructure sectors are covered in all the studies shown in Table 12.4. For example, electricity supply is addressed in all of them, while food supply is covered in only a few. Because the studies include different types of infrastructure, they are therefore difficult to compare. GHGs embodied in built environment construction materials – primarily cement use on an annual basis each year in the community – are of the order of 2% of the CIF for Denver and much higher (at ~10%) in Delhi, India. The CIF presently does not include energy embodied in other infrastructure materials such as iron or copper, although, national inventory data suggest their contributions are likely to be lower than that of cement.

Table 12.4: Studies that have estimated GHG emissions of various infrastructure sectors for select cities

			Trans-Boundary Infrastructures Serving Whole Community					
Reference	**Cities/Urban Areas in Study**	**Electricity**	**Water**	**Fuel**	**Cement or other construction materials**	**Food**	**Air Travel**	**Freight**
(Sovacool and Brown, 2010)	Beijing, Delhi, Jakarta, London, Los Angeles, Manila, Mexico City, New York, Sao Paolo, Seoul, Singapore, Tokyo	✓		✓				
(Ramaswami et al., 2008b)	Denver	✓	✓	✓	✓	✓	✓	
(Ngo and Pataki, 2012)	Los Angeles	✓	✓			✓		
(McGraw et al., 2010)	Chicago	✓						✓
(Kennedy, Steinberger, et al., 2009b)	Bangkok, Barcelona, Cape Town, Denver, Geneva, London, Los Angeles, New York, Prague, Toronto	✓		✓			✓	
(Hillman and Ramaswami, 2010b)	Arvada, Austin, Boulder, Denver, Fort Collins, Minneapolis Portland, Seattle	✓	✓	✓	✓	✓	✓	✓
(Hillman and Ramaswami, 2010b)	Melbourne	✓	✓	✓	✓	✓	✓	
(Chavez et al., 2012)	Delhi	✓	✓	✓	✓	✓	✓	
(*Le Bilan Carbone de Paris: Bilan des émissions de gaz à effet de serre*, 2009)	Paris	✓			✓	✓	✓	
(Sharma et al., 2002)	Calcutta, Delhi	✓			✓	✓		
(Kennedy, Ramaswami, et al., 2009)	44 global cities	✓	✓	✓			✓	
(Cui, 2010)	Xiamen City, China	✓	✓	✓	✓	✓	✓	
(Chandler et al., 2011)	King County	✓	✓	✓	✓	✓	✓	
("ICLEI Member List")	~40 US city/counties	✓						
(*Energy and Carbon Emissions Profiles of 54 South Asian Cities*)	54 South Asian cities	✓	✓					

12.3.2.4 Dynamic Observations on Infrastructure Materials Use and Stocks

Infrastructure-based GHG emission footprints of cities (CIF as shown in Figure 12.5) highlight the relatively large impact that urban construction materials have on overall annual GHG indirect emissions, particularly in rapidly developing cities such as Delhi where >10% GHG emissions in one year were attributed to cement use in construction in the city.

Developing world cities in the early phases of urbanization have a much lower stock per capita compared to developed countries, and are poised to grow along an S-shaped curve (Ausubel and Herman, 1988), with aspirations toward the stocks prevalent in industrialized country cities. Differences in infrastructure stock between developing and industrialized countries result in fundamentally different boundary conditions for climate change mitigation. During early phases of urbanization, industrial emissions (e.g., to produce the materials needed for construction) tend to be much higher than in mature phases of urbanization or urban shrinkage.

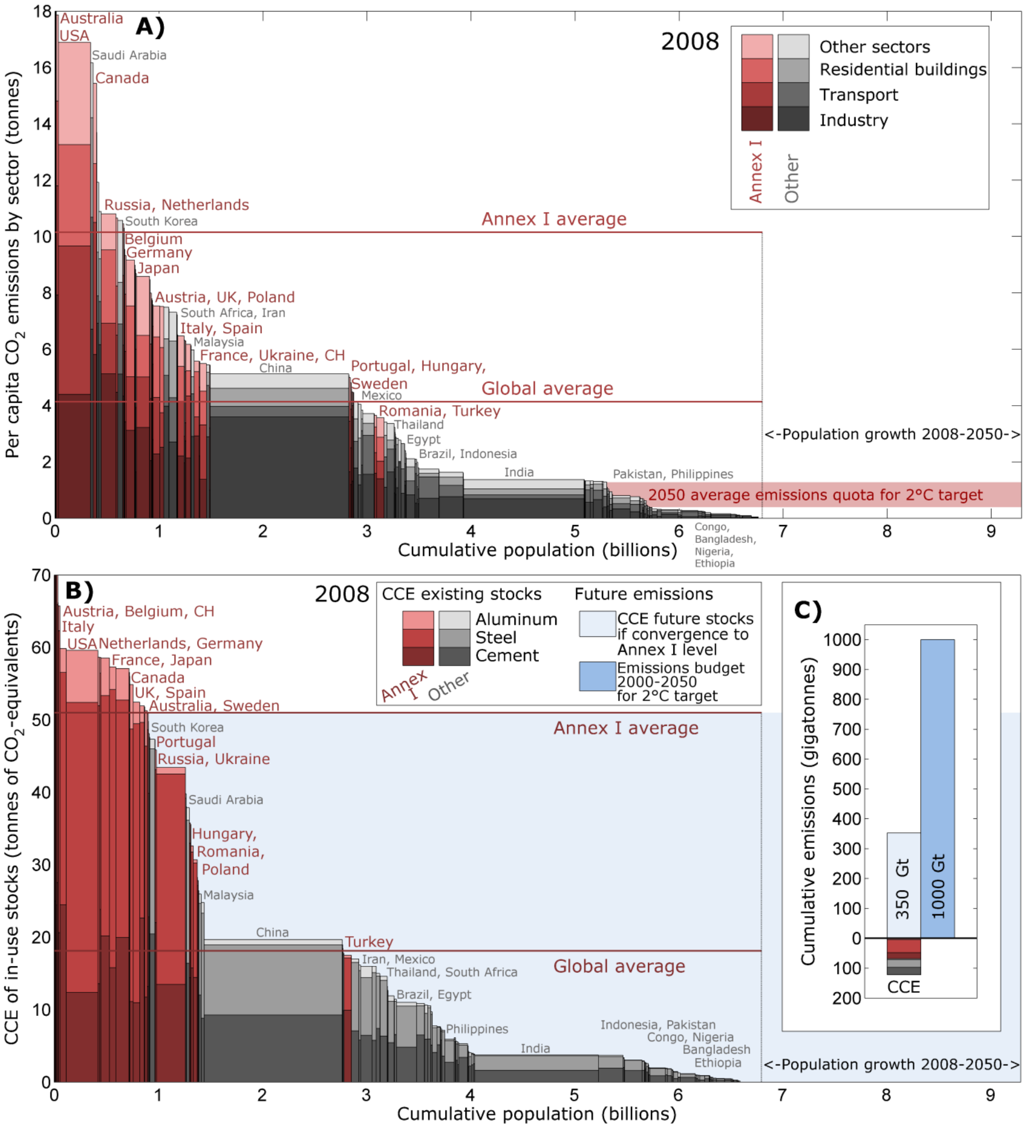


Figure 12.8. (A) Total energy-related CO_2 emissions per-capita by country (red and grey bars) compared to global per-capita emission level in 2050 to reach 2°C target with a 50-75% probability (red horizontal bar); (B) CCE per capita of existing stocks by country (red and grey) and of to be built stocks if developing countries converge on the current Annex I level (light blue); (C) comparison with emission budget for the period 2000-2050 to reach the 2°C target with a 75% probability. Out of this emission budget (1000 Gt), about 420 Gt has already been used up in the period 2000-2010. (Source: Müller et al., 2013).

The differences in per capita infrastructure stock between developing and industrialized nations–termed the infrastructural gap—has been quantified by (Müller et al., 2013), who define Current Carbon Equivalent (CCE) as the expected greenhouse gas emissions released if the stock were re-built using current standard technologies based on primary production. They quantified the CCE of the global and national cement, steel, and aluminium stocks (which account for about 47% of total industry emissions and most of materials production emissions) and found that in 2008, the global infrastructure embodied 122 (-20/+15) Gt CO2-eq, with 68 (-13/+10) Gt CO2-eq in Annex I countries and 53 (±6) Gt CO2-eq in non-Annex I countries (Figure 12.8B). Accordingly, the existing infrastructure of the average Annex I citizen is worth 51 (-10/+7) t CO2-eq, three times that of the World average citizen's infrastructure with 18 (-3/+2) t CO2-eq, and about five times higher than that of the average non-Annex I citizen with 10 (±1) t CO2-eq. In comparison, the total global anthropogenic CO2 emissions excluding agriculture, forestry and land use change were about 30.9 Gt or 4.6 t per capita in 2008 (European Commission and Joint Research Centre/Netherlands Environmental Assessment Agency, 2011). Thus, the current material stock is worth about 4 years of current total CO2 emissions. In summary, the future growth in stocks will occur in the developing world and will require a greater share of the anticipated future energy growth.

12.3.3 Current trends in aggregate urban and rural emissions

We use the EDGAR database (v4.2), which characterizes global emissions of greenhouse gases, to calculate trends in urban and rural emissions. Global emissions of carbon dioxide have increased from 28.5 Gt in 1990 to 36.9 Gt in 2008 (Figure 12.9). Direct emissions associated with human settlements account for 75-81% of global CO_2 emissions from 1990 to 2008. Areas with urban populations are responsible for 29.9 to 35.7% of global CO_2 emissions from 1990 to 2008, and for 4.7 (56%) of 8.3 Gt increase in emissions over that period. The share of emissions from rural areas has not increased, remaining in the range 43.2 to 45.5%. An increase of 3.8 Gt (46%) is attributed to direct emissions in areas with rural populations, while other emissions have decreased 0.2 Gt (-2%) due primarily to variability in large-scale biomass burning. Emissions from large-scale biomass and shipping and aviation (which were not assigned to urban or rural areas) account for the remaining 18.2 to 24.2% (6.9 to 8.4 Gt CO_2).

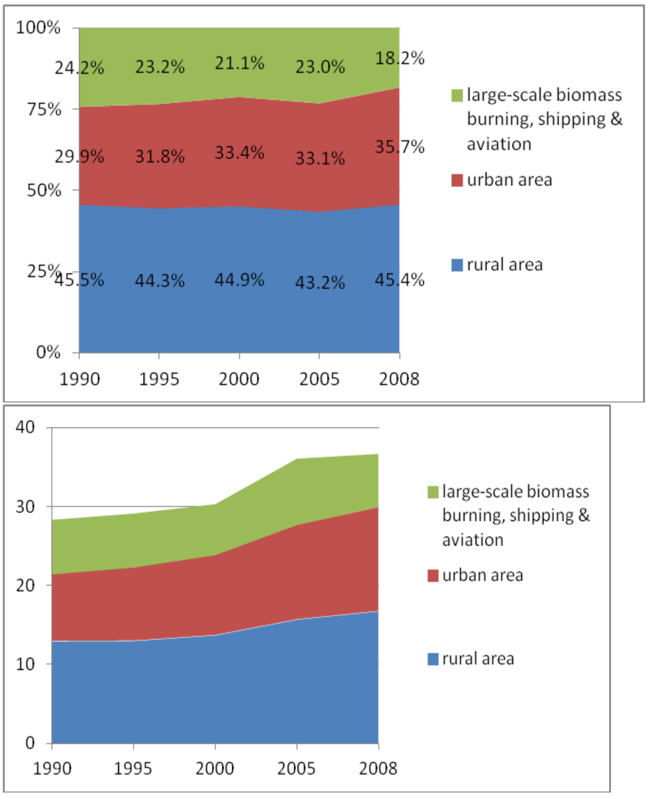


Figure 12.9. A. Percent of Global CO_2 Direct Emissions by Populated Areas. B. Global CO_2 Direct Emissions (Gt) by Populated Areas. (Source: JRC/PBL, 2012)

Another study using EDGAR for the 2000 attempted a Scope 1 & 2 analysis by estimating a range of urban emissions levels for CO_2 and three other gases (CH_4, N_2O and SF_6) through identifying the direct emissions (low estimate) and also allocating all emissions from thermal power plants outside urban areas to cities (high estimate). It also differs from the previous study because it includes aviation and navigation-related emissions within the urban area. Based upon this approach total anthropogenic CO_2-eq. emissions, excluding emissions from large scale biomass burning, were approximately 34.8 billion metric tons, of which urban GHG emissions range between 38 and 49% of total emissions or between 12.8 and 16.9 Gt (Marcotullio et al.) (Table 12.5). African urban GHG emission's shares are lowest ranging from ~21-30% of total African CO2-eq. emissions. In contrast, North American urban CO2-eq. emission's shares are highest of total North American GHG emissions, ranging from 49-73%. Amongst developing countries, urban CO_2-eq. emissions range from approximately 26-33% of total emissions. In the developed world, urban CO_2-eq. emissions range from approximately 47-63% of total.

Table 12.5: Percent urban share of total CO_2-eq. emissions, by sector by region, 2000. (Source: Marcotullio et al.)

Sector	Africa	Asia	L. America & Car	Europe	N. America	Oceania	All Urban
Ag.	2.4	6.0	2.2	9.0	5.0	4.9	5.3
Ene.	31.7	38.1	35.5	50.5	41.4	35.3	41.5
Ind.	40.5	30.4	33.3	47.5	50.9	25.4	38.1
Res.	14.5	24.7	27.1	40.0	60.3	33.3	36.9
Trans.	30.4	34.3	38.9	47.3	68.4	56.3	50.9
Waste	18.7	32.6	40.4	40.5	64.1	50.9	38.8
Urban (low)	21.4	29.8	24.8	44.8	49.2	30.3	36.8
Urban (high)	29.5	37.9	29.3	55.0	72.8	50.2	48.6

Notes: “Ag.” = agriculture; “Ene” = energy, “Ind.” = industrial, “Res” = residential, “Trans” = transportation, ‘Waste” = waste management.

12.3.3.1 Sectoral emissions in populated urban and rural areas

We assigned emissions to grid cells and apportioned them according to areas having urban or rural populations. We identified four sectors excluding large-scale biomass, shipping and aviation. Energy production had the greatest CO_2 emissions, followed by use-phase activities such as buildings and transportation fuel combustion (Figure 12.4), and the combination of materials production and manufacturing (

Figure **12.10**). Carbon dioxide emissions from waste management was relatively small. Agriculture was not considered, since large-scale biomass burning was excluded.

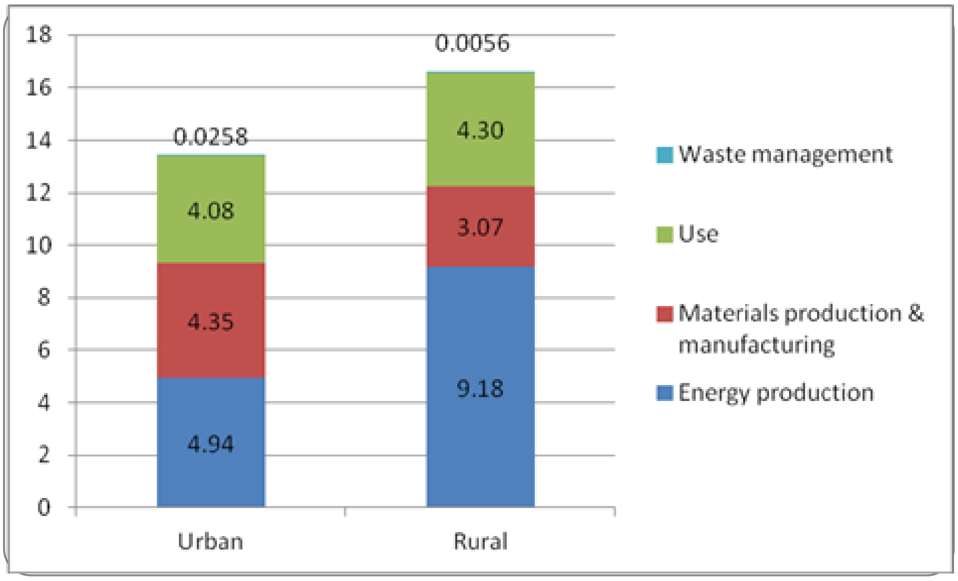


Figure 12.10. Global CO_2 emissions (Gt) by sector in 2008, urban and rural areas. IPCC calculations based on EDGAR data.

These estimates are similar to another study also showing that the energy sector accounted for the largest share ranging reach from 54-65% of total urban CO_2-eq. emissions (Marcotullio et al.) (Table 12.6). Agricultural activities provided the lowest share with approximately 2% of total urban CO2-eq. emissions. Transportation accounted for 20% of total GHG emissions with road transportation CO_2-eq. making up over 90% of this source (the other components being aviation, navigation and non-road sources).

There were significant differences in urban source share between developing and developed countries. In the developing countries energy production ranged between 61 and 70% of all urban GHG emissions, while in the developed world energy production accounted for between 50 and 63%. Urban transportation emissions accounted for approximately 11% of all urban GHG emissions in the developing world, while the same category accounted for almost 25% in the developed world's cities. Agricultural, industrial and waste urban GHG emissions were larger in share in the developing world (4%, 10% and 7%) than in the developed world (1%, 9% and 3%). On the other hand, residential GHG emissions in urban areas of the developed world (11% of total) were almost twice as important as those of the developing world (6% of total).

Table 12.6: Share of total urban CO_2-eq. emissions, by source by region, 2000. (Source: Marcotullio et al.)

Sector	Africa	Asia	L. America & Car	Europe	N America	Oceania	All Urban
Ag.	3.14	3.52	2.92	1.57	0.57	4.24	2.07
Ene. (low)	63.84	61.35	45.88	57.16	43.20	56.09	54.13
Ene. (high)	73.79	69.61	54.15	65.10	61.59	73.46	65.31
Ind.	8.31	11.37	10.45	11.89	4.85	4.02	9.41
Res.	5.30	7.64	6.39	10.82	12.05	3.53	9.64
Trans.	13.22	10.15	25.00	15.74	35.01	27.40	20.01
Waste	6.19	5.97	9.36	2.82	4.32	4.71	4.74

Notes: "Ag." = agriculture; "Ene" = energy (low and high estimate), "Ind." = industrial, "Res" = residential, "Trans" = transportation, 'Waste" = waste management.

12.3.3.2 Emissions due to activities by urban versus rural populations

The estimates using the EDGAR database show that CO2 emissions from different sectors are not evenly divided between urban and rural areas (Figure 12.11). Urban areas have the dominant shares of carbon dioxide emissions from waste management (82%), and the combination of materials production and manufacturing (85%), while rural areas have the dominant shares of CO2 emissions from use-phase activities (51%) and energy production (65%).

Urban areas often import energy from power plants located in rural areas and goods manufactured in rural areas. In the EDGAR database, 5,116 (49%) of 10,351 cells having power plants in 2007 were classified as urban. Electricity consumed in urban areas accounts for 67% of greenhouse gas emissions related to energy (IEA, 2008). The Global Energy Assessment (GEA, 2012) estimated that 76% of final energy is the urban contribution. To account for activities by urban populations, some of the CO2 emissions from power plants, industrial and manufacturing facilities located in rural areas need to be attributed to urban populations. The EDGAR database provides estimates of carbon dioxide emissions by power plant. Virtually all power plant emissions are located in populated areas. Emissions from power plants in urban areas accounted for 1.77 Gt (23% of all power plant emissions of carbon dioxide) in 1990, and have consistently risen to reach 4.00 Gt (33%) in 2008.

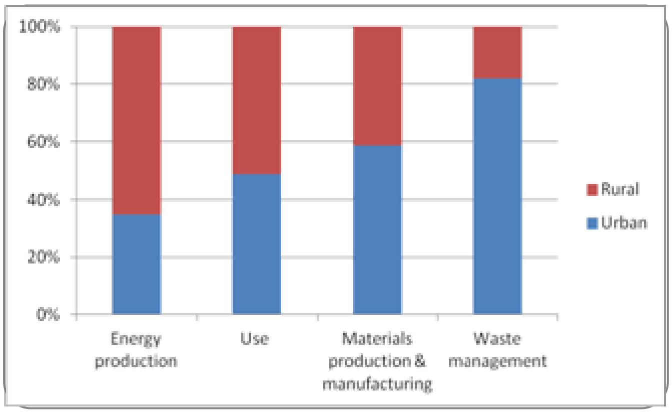


Figure 12.11. Percent of human settlement carbon dioxide emission from urban and rural areas in 2008. (Source: Marcotullio et al.)

In terms of intensity, except for transportation and energy production, urban CO_2-eq. emissions per capita are lower than non-urban CO_2-eq. emissions per capita in all regions (Marcotullio et al.). This is true for both the low- and high- estimates of urban CO_2-eq. emissions. There is one regional exception to this pattern. In Asia, the high urban CO_2-eq. emission per capita estimate was approximately the same as that of the non-urban sector. Moreover, CO_2-eq. emissions from the world's cities averaged 5.2 tons per capita (low estimate) and 6.87 tons per capita (high estimate), while global average is 5.7 tons CO_2-eq. per capita. The global non-urban emissions average 6.08 tons per capita,. The high estimate urban emission level equals or exceeds the regional level in Africa and Asia, but remain below the urban range of emissions per capita in all other regions. The global non-urban levels do not exceed those of the urban (high) estimates due to the effects of both the large proportion of urban dwellers in the developed world and the high share of total emissions from urban areas in these countries. When all countries are aggregated, the urban values from the developed urban world outweigh those from the developing world.

12.3.3.3 Largest urban total GHG emissions and GHG emissions per capita

The largest urban GHG emitters tended to be the largest populated urban areas, although not all high population cities made the list (Table 12.7). For example, among the top 15 GHG emitters were the metropolitan areas of Tokyo, New York, Los Angeles, Chicago, Seoul, Essen, Taipei, Moscow, Shanghai, San Jose, Boston, Houston, Detroit, Baltimore and London. All of these urban extents included populations larger than 4 million and 10 had populations of over 10 million. Missing from this list were the metropolitan areas with populations of over 10 million including Jakarta, Sao Paulo, Mumbai, Delhi, Mexico City, Kolkata, Cairo, Manila, Buenos Aires, Tehran, Karachi, Rio de Janeiro and others. These 15 cities account for approximately 23% of total urban GHG emissions and 8.6% of total global GHG emissions.

On the other hand, the largest per capita emitters include such urban areas as Traralgon, Australia; Farmington, US; Asbest Russia; Cottbus, Germany; Guelma, Algeria; Owensboro, US; Standerton, South Africa; Achinsk, Russia; Grevenbroich, Germany;Fairmont US; Kozsni, Greece; Anugul, India; Rockhampton, Australia; and Cerepovec and Magnitogorsk, Russia (Table 12.7). These locations tend to be smaller urban centers (typically with populations under 200,000 with many under 100,000), with specific economic functions; energy production, industry, fossil fuel mining or refining and large scale livestock centers. The total emissions from these centers are much lower than the larger urban areas, but due to low populations they have high per capita contributions. These urban areas can be classified as net-producing cities. The aggregate emissions from these urban areas are much lower than the group above. The CO2-eq. emissions levels from all 15 urban areas account for approximately 2.6% of total urban GHG emissions and < 1.0% of total global GHG emissions. It is only due to low populations they stand out as high per capita contributors.

Table 12.7: Top 15 highest GHG urban extent emitters, 2000
(mil tons CO2-eq and tons CO2-eq./cap) (Source: Marcotullio et al. submitted, based on EDGAR)

Urban area	Pop (mil)	Total emission range	per capita emission range
Tokyo, JP	76	644.1 - 644.4	8.4 - 8.45
New York, US	27	442.1 - 443.9	16.6 - 16.71
L. Angeles, US	18	266.7 - 270.0	14.6 - 16.71
Chicago, US	11	211.6 - 213.8	19.97 - 20.18
Seoul, KOR	21	171.9 - 171.2	8.23 - 8.24
Essen, GER	11	171.5 - 171.6	16.18 - 16.19
Taipei, TWN	18	165.5 - 165.6	9.08 - 9.09
Moscow, RUS	15	157.9 - 158.2	10.64 - 10.66
Shanghai, CHN	15	133.5 - 137.9	8.81 - 9.10
San Jose, US	8	116.9 - 119.1	14.08 - 14.34
Boston, US	7	115.6 - 117.7	16.34 - 16.63
Houston, US	4	98.8 - 122.3	22.84 - 28.28
Detroit, US	4	97.5 - 100.2	21.94 - 22.54
Baltimore, US	7	95.0 - 97.6	14.46 - 14.85
London, UK	13	92.4 - 93	7.11 - 7.15

Note that some of these urban extents represent large urban areas and not individual cities. For example, Tokyo includes the megalopolis that extends from Tokyo to Nagoya. New York includes the metropolitan region from New York City to Philadelphia.

12.3.4 Future trends in urban emissions

12.3.4.1 Direct emissions from existing infrastructure

Scenarios of global CO2 emissions estimate 496 Gt of CO2 associated to existing infrastructure from 2010 and 2060 (from a range of 282 to 701 Gt of CO2) (Davis et al., 2010). A continued expansion of fossil fuel-based infrastructure would produce cumulative emissions of 2986 to 7402 Gt of CO2 during the remaining of the 21st century leading to atmospheric concentrations greater than 600 ppm, a context in which the primary threat are devices and infrastructure that do not yet exist (Davis et al., 2010). Primary energy infrastructure represents the largest commitment to future emissions with an average cumulative of 224 Gt of CO2 before 2060. It is followed by transport infrastructure with an average of 115 Gt of CO2, and industrial equipment with 104 Gt of CO2 (being cement and steel industries the major contributors) (Davis et al., 2010). China alone accounts for roughly 37% of the global emissions commitments as it is experiencing a dynamic industrialization and urbanization process; United States adds 15%; Europe 15%, and Japan 4%, totalizing 71% of total global emissions commitments by 2060 (Davis et al., 2010).

There is consensus on the need to overcome high-carbon infrastructure lock-in and thus, to seek a successful commissioning of a new generation of devices and integrated infrastructure that can provide low carbon energy and services, but even more, that can shape low carbon settlements of the future.

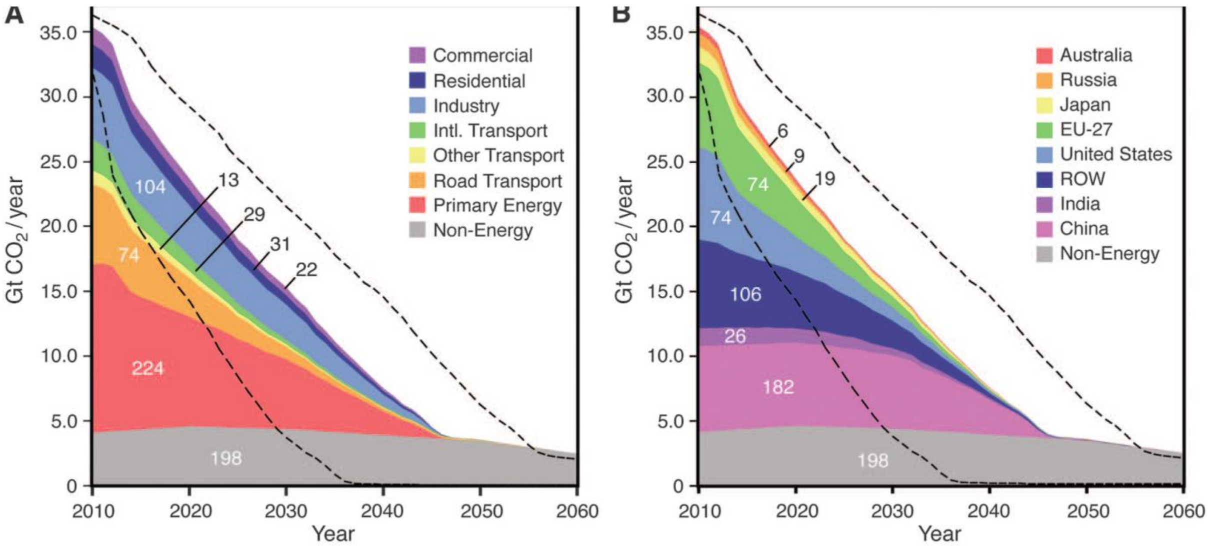


Figure 12.12. Scenario of CO2 emissions from existing energy and transportation infrastructure by industry sector (A) and country/region (B) (Davis et al., 2010)

12.3.4.2 Indirect emissions from existing infrastructure

Based on the calculations for the current carbon equivalent (CCE) of the existing infrastructure stocks, (Müller et al., 2013) make a crude estimate for potential future emissions from infrastructure development (see Figure 12.8 B&C): They find that, if global population will grow to 9.3 billion by 2050 (UN Population Division, 2012), developing countries will expand their built environment stocks to the current level of industrialized countries, and industrialized countries will forego future stock expansion, the CCE of the global infrastructure would grow from currently 122 Gt CO_2-eq to about 470 Gt, with 350 Gt of emissions still to be expected from primary production alone. In comparison, limiting average global temperature rise to 2°C above pre-industrial levels requires that cumulative emissions during the 2000-2050 period do not exceed 1000 to 1500 Gt CO_2 (probability of reaching target with 75% or 50%) (Meinshausen et al., 2009). In the period 2000-2010, an estimated total of 420 Gt CO_2 has already been cumulatively emitted due to human activities (including deforestation) (Meinshausen et al., 2009), leaving an emission budget of about 600 to 1100 Gt CO_2 for the period 2010 to 2050. Given the large amount of current emissions not related to materials (Figure 12.12), it becomes apparent that the scaling up of Western type infrastructure stocks to the global level would form a major challenge for reaching the 2 °C target.

12.3.4.3 Direct emissions from future urban expansion

There are three published studies of future urban expansion (Table 12.8): (1) a meta-analysis of global patterns of urbanization (Seto et al., 2011), (2) an analysis of global urban expansion based on a large sample of cities (Angel et al., 2011), and (3) spatially-explicit probabilistic forecasts of global urban expansion through 2030 (Seto et al., 2012). Another study combined the forecasts from these scenarios with three CO_2 per unit cement scenarios, to estimate the increase in direct emissions from forecasted urban expansion (Güneralp and Fragkias, Submitted). That study found that, across the forecasts, Asia emerges by far as the region with the largest CO_2 emissions due to cement demand. Its forecasts range from 9 Gt CO_2 in B1—CC3 to 63 Gt CO_2 in A1—CC1 (Figure 12.13A-C).

The contribution of Asia to the total emissions ranges from an average of 30 percent across Angel et al (2011) scenarios to an average of 60 per cent across Seto et al (2011) scenarios, with an overall average of 47 per cent across all scenarios. The contributions of China and India to the emissions from Asia, respectively, are about 35 per cent and 20 per cent, on average, across all scenarios except those from Angel et al that do not report separate urban expansion figures for the two countries. Land Rich Developed Countries in Angel et al (U.S., Canada, and Australia) show a wide range (Figure 12.13B), primarily caused by the density levels assumed in each of their three urban forecasts. The same is true for Europe and Japan. The 24 forecasts of CO_2 emissions for the whole world range from 16 Gt CO_2 to 115 Gt CO_2, for B1—CC3 and A1—CC1 scenarios, respectively. For the scenario with the largest forecasted global urban expansion (A1), the CO_2 emissions range between 103 Gt CO_2 and 115 Gt CO_2 (Figure 12.13D).

Table 12.8: Urban expansion forecasts according to the various scenarios in the three published studies.

Study	Scenario	Forecasted Urban Expansion to 2030 (km^2)						
		Africa	**Asia**	**Europe**	**LAmerica**	**NAmerica**	**Oceania**	**TOTAL**
(Seto et al., 2011)	A1	107,551	1,354,001	296,638	407,214	73,176	16,996	2,255,576
	A2	113,423	702,772	162,179	122,438	49,487	15,486	1,165,785
	A3	107,551	1,238,267	232,625	230,559	86,165	18,106	1,913,273
	A4	136,419	989,198	180,265	131,016	74,572	15,334	1,526,805
		Africa	**Asia**	**East Asia and the Pacific**	**Europe and Japan**	**LAmerica and the Caribbean**	**Land Rich Developed Countries**	**TOTAL**
(Angel et al., 2011)	B1	58,132	120,757	43,092	9,772	49,348	54,801	335,902
	B2	92,002	203,949	75,674	74,290	98,554	119,868	664,337
	B3	137,722	316,248	119,654	161,379	164,975	207,699	1,107,677
		Africa	**Asia**	**Europe**	**LAmerica**	**NAmerica**	**Oceania**	**TOTAL**
(Seto et al., 2011)	C	41,450	225,825	151,075	93,525	130,500	10,450	652,825

Across the three CO_2 per cement scenarios in Güneralp and Fragkias (submitted), the differences in the total CO_2 emissions are notable especially for the developing regions; however, these differences are small compared to the scale of forecasted urban expansion in all three studies (Figure 12.13 A-C). For example, the average for the total CO2 emissions from future urban expansion over all eight urban expansion scenarios range from 56 Gt to 62 Gt CO_2, a mere 6 Gt difference across the three CO_2 per cement scenarios. On the other hand, the average for the total CO_2 emissions from future urban expansion over the three CO_2 per cement scenarios ranges from 60 Gt CO_2 to 83 Gt CO_2 across the three sets of urban expansion scenarios (after first taking the average of the forecasted CO_2 emissions for each of the three urban expansion studies). The findings from their analysis suggests that, given the scale of forecasted urban expansion, the spatiality of urban growth may have a larger affect on emissions than efficiency gains in cement production.

12.3.4.4 Future emissions under different scenarios of urban expansion and population growth

Estimates of future emissions under different urbanization scenarios show that the type of urban development will have a larger impact on emissions than the amount of urban population growth (Seto, Sanchez-Rodriguez, et al., 2010). A low fertility, low density urbanization future will result in higher greenhouse gas emissions than under a high fertility, high or medium density urbanization future. Asia is a major region of concern for the potential effects of future urban populations. Scenarios show that savings in emissions from different types of urban development and associated lifestyles are tremendous, irrespective of the fertility rate. With the low fertility scenario, if the growth in urban population over the next forty years leads to low density cities such as Washington,

D. C., this would result in an increase of 380 Gt of emissions in 2050. These calculations do not include emissions leading up to 2050, only emissions in the year 2050. In contrast, if the growth in urban populations occurred predominantly in high density cities like Seoul, the high fertility

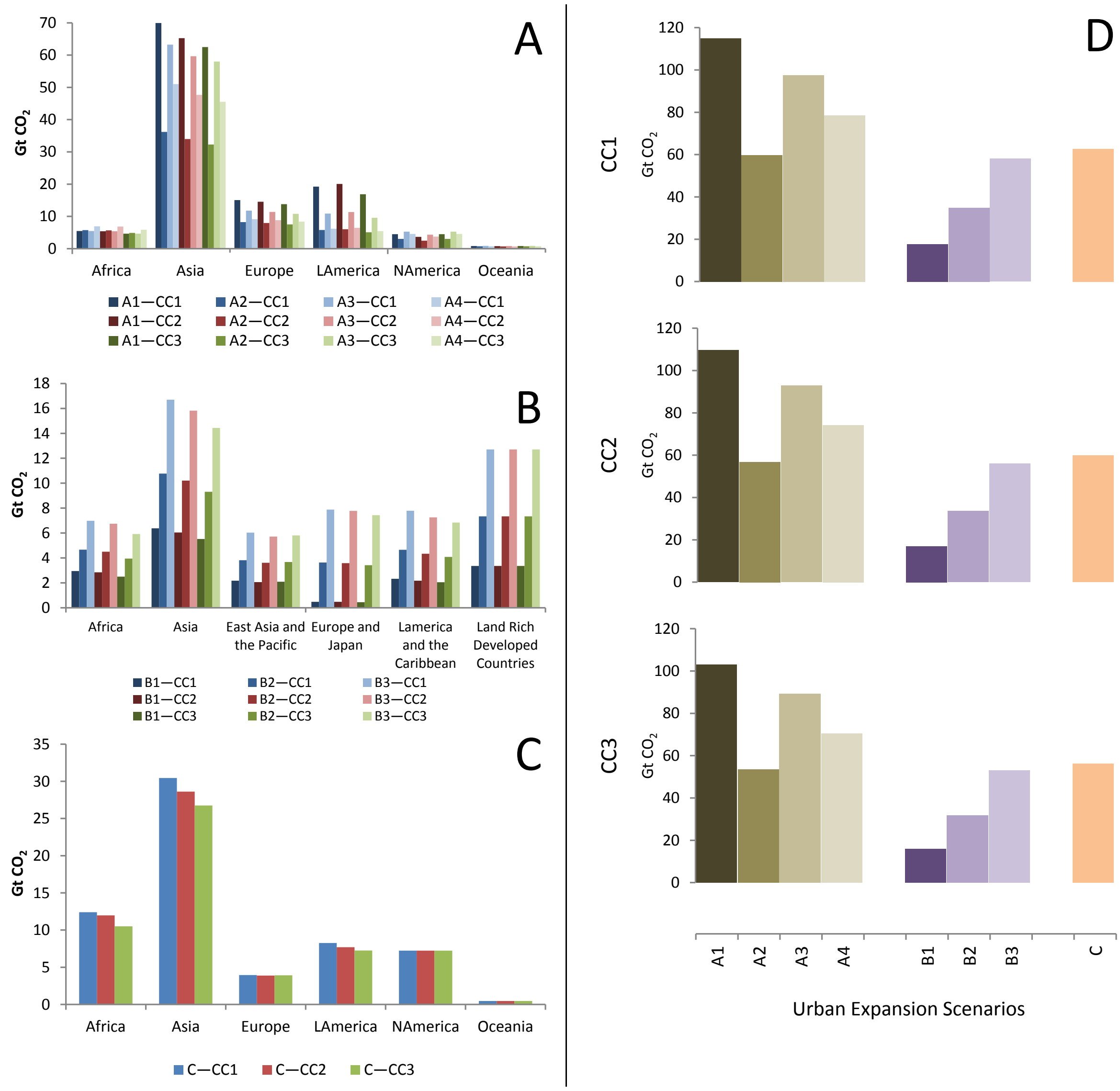


Figure 12.13. CO2 emissions from forecasted urban expansion, 2000-2030. Regional breakdowns of forecasted emissions based on urban expansion forecasts from (A) Seto et al (2011), (B) Angel et al (2011),(C) Seto (2012), and three CO2 per unit cement scenarios, CC1-3, and (D) total forecasted emissions.

scenario generates only a total of 152 Gt in 2050, less than half of the total emissions under a low fertility, low density scenario. The constant fertility scenario coupled with low urban densities produces the highest emissions (937 tonnes), but this is the least likely population growth scenario.

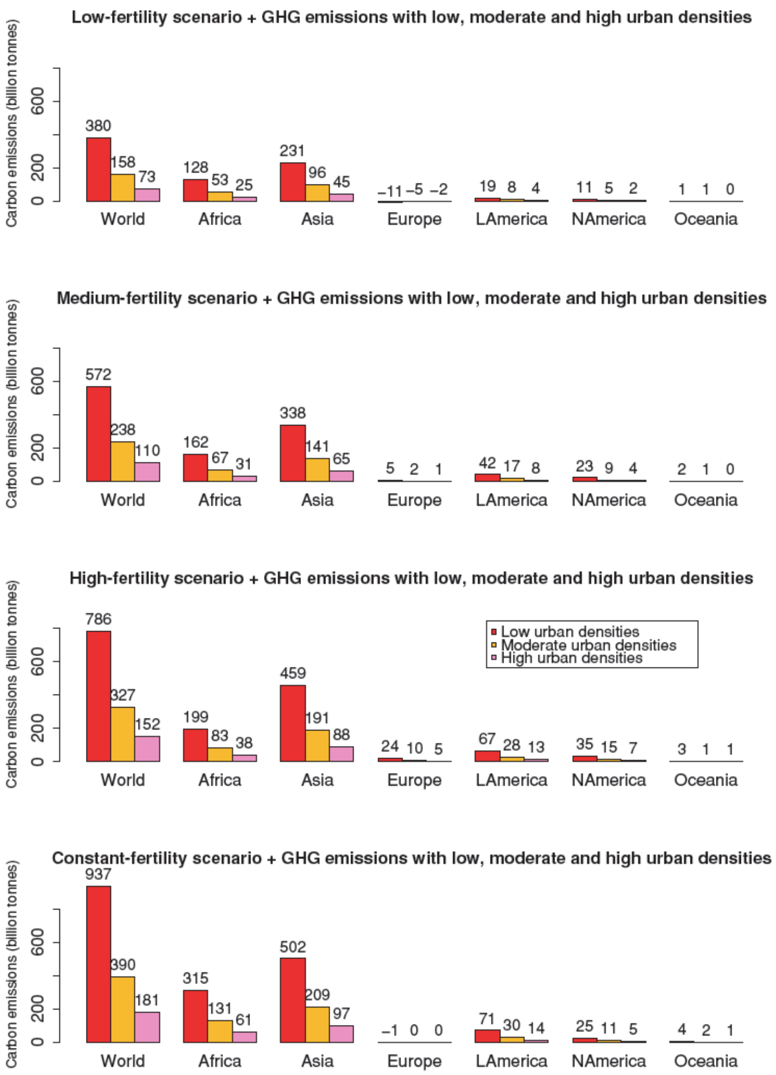


Figure 12.14. Estimates of carbon emissions based on urban population growth and types of urban settlements. Source: (Seto, Sanchez-Rodriguez, et al., 2010).

FAQ 12.2: How much do urban areas contribute to greenhouse gas emissions?

Urban areas consume approximately 60-80% of final energy globally. For the period 1990 to 2008, direct emissions associated with human settlements account for 75-81% of global CO2 emissions. However, there is large variation in urban emissions across countries and regions. For example, African urban GHG emissions are approximately 21-30% of total African CO2-eq. emissions. In contrast, North American urban CO2-eq. emissions are estimated to be 49-73% of total North American emissions.

12.4 Urban form and infrastructure

Urban form is defined as "the spatial pattern of large, inert, permanent physical objects in a city" (Lynch 1981, 47). These patterns typically include the spatial configuration of land use, transportation systems, and urban design elements (Handy 1996). In this chapter, urban form refers to the overall urban pattern, including spatial extent, spatial configuration, and internal pattern of settlements, including the layout of streets and buildings. Urban form is dependent on spatial scale.

12.4.1 Characteristics of low carbon settlements

There is evidence that urban form, design, and connectivity are important in shaping the levels of urban GHG emissions, but these relationships are not absolute. Urban form is responsible directly for a large proportion of consumed energy and indirectly influences the patterns and modes of energy consumed in everyday activities (Rickwood et al., 2008). Low carbon societies (Skea and Nishioka, 2008) and low carbon cities (Gossop, 2011) are human settlements that have physical and operational characteristics associated with low GHG emissions. A meta-analysis of over 200 studies on travel and the built environment (Ewing and Cervero, 2010) identified several features of urban form that affect vehicle miles travelled and energy use, indicating that human settlements could meet low carbon targets by attaining and sustaining the following spatial characteristics: (1) high population and employment densities that are co-located; (2) compact urban form; (3) mixed land uses; (4) high connectivity; (5) destination accessibility terms of job accessibility by auto, by transit and by distance to downtown, often referred to as regional accessibility; and (6) integrating multiple transport modes (Figure 12.15).

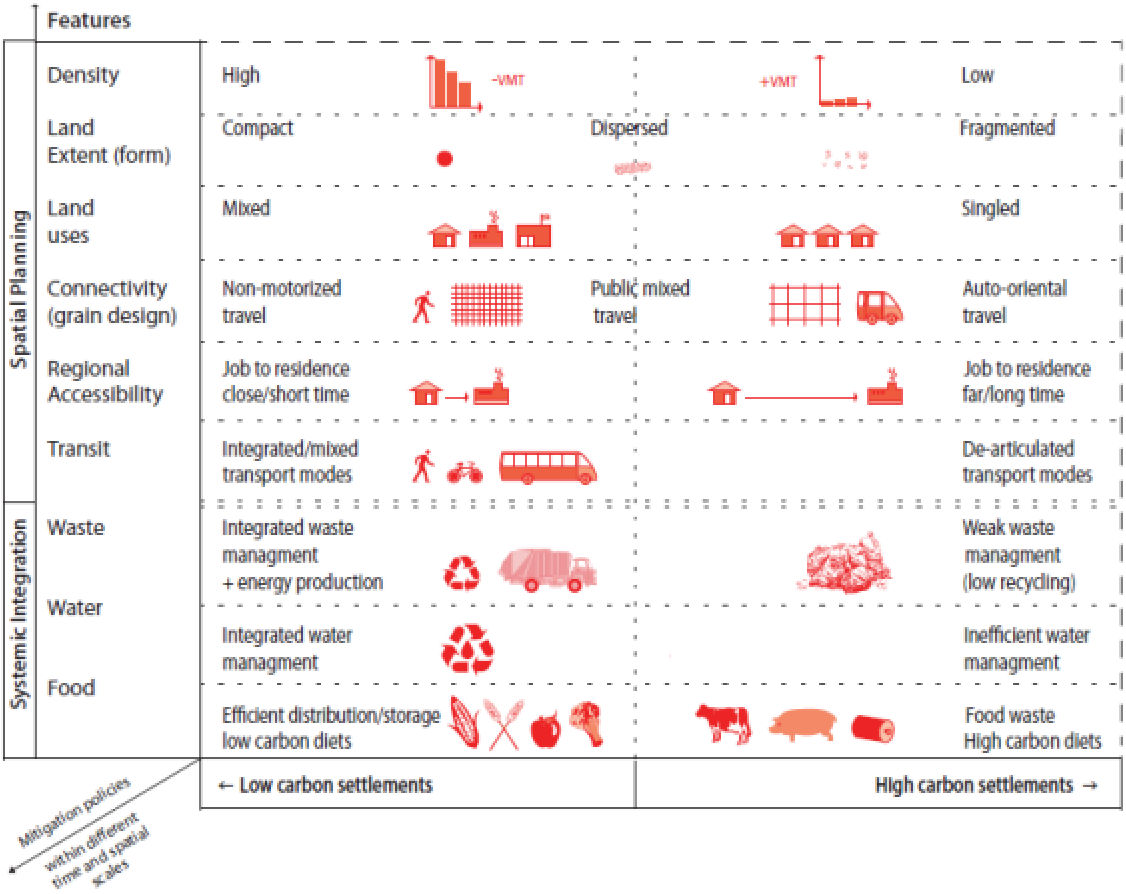


Figure 12.15. Characteristics of low- and high-carbon settlements

12.4.2 Density: co-located high population and employment density

Density affects transport patterns in two ways. First, higher urban densities contribute to the reduction of average travel distances for both work trips and shopping trips (Frank and Pivo, 1994). Second, higher density encourages a switch toward less energy intensive transportation modes (e.g., public transport, walking, and cycling). The influence of density on transportation mode choice is stronger than other non-urban form variables such as economic ones (Frank and Pivo, 1994; Cervero, 2008).

There is strong empirical evidence that high demographic (population, household) density coupled with employment/job density could lower transport energy. In the U.S., doubling residential density could lower household vehicle miles traveled by about 5 to 12 percent, and perhaps as much as 25 percent, if coupled with higher employment concentrations, significant public transit improvements, mixed land uses, and other supportive demand management measures (NRC, 2009). Taking into account construction materials for infrastructure, building operations, and transportation, a low-density, leapfrog or disconnected, single-use (often residential) development is more energy and GHG intensive than high-density, mixed-use development on a per capita basis. Higher densities also have economic co-benefits (Newman and Kenworthy, 1999a), such as higher wages (Hoch, 1976, 1980), and more efficient use of infrastructures and energy (Forsyth et al., 2007).

As population density increases, per capita electricity demand decreases (Figure 12.4). For instance Japan's urban areas are around five times denser than Canada's. Japan's per capita consumption of electricity is also around 40% that of Canada's. Similarly, Denmark's urban areas are denser than Finland's by a factor of four. Denmark's per capita electricity consumption is around 40% that of Finland's (Kamal-Chaoui and Robert, 2009, pp. 9–10).

Demographic density is strongly correlated with built density, but built density is often mistaken for verticality, whereas there is no equivalence between high rise and high density (Vicky Cheng, 2009; Salat, 2011). Medium-rise (less than seven-floor high) urban areas with a high building footprint ratio can have a higher built density than high-rise urban areas with a low building footprint. Often, high-rise, high-density urban areas lead to a trade-off between building height and spacing between buildings. The higher the buildings, the more they have to be spaced out to allow light penetration (Figure 12.16). The cost of construction per square meter increases as buildings become higher, due notably to structure material costs (Picken and Ilozor, 2003; Blackman and Picken, 2010). High-rise buildings imply higher energy costs in terms of vertical transport, but also in terms of heating, cooling, and lighting due to low passive volume ratios (Ratti et al., 2005; Salat, 2009). Medium-rise, high-density urban areas can achieve similar levels of density as high-rise, high density developments but require less materials and embodied energy (Picken and Ilozor, 2003; Blackman and Picken, 2010). Their building operating energy levels are lower due to high passive volume ratio (Ratti et al., 2005; Salat, 2009). Experience across cities shows that floor area ratio (FAR), the ratio of floor area over the land area, is an effective policy tool to increase urban density.

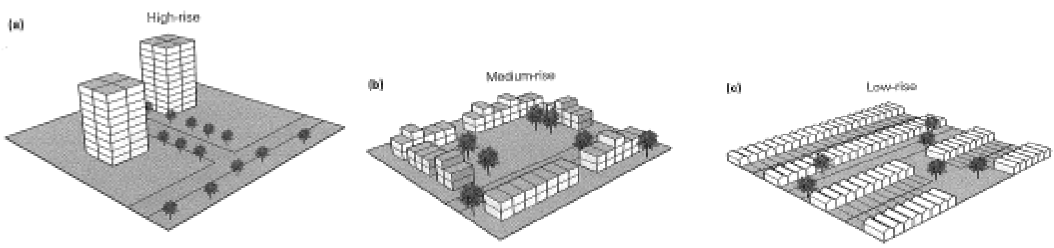
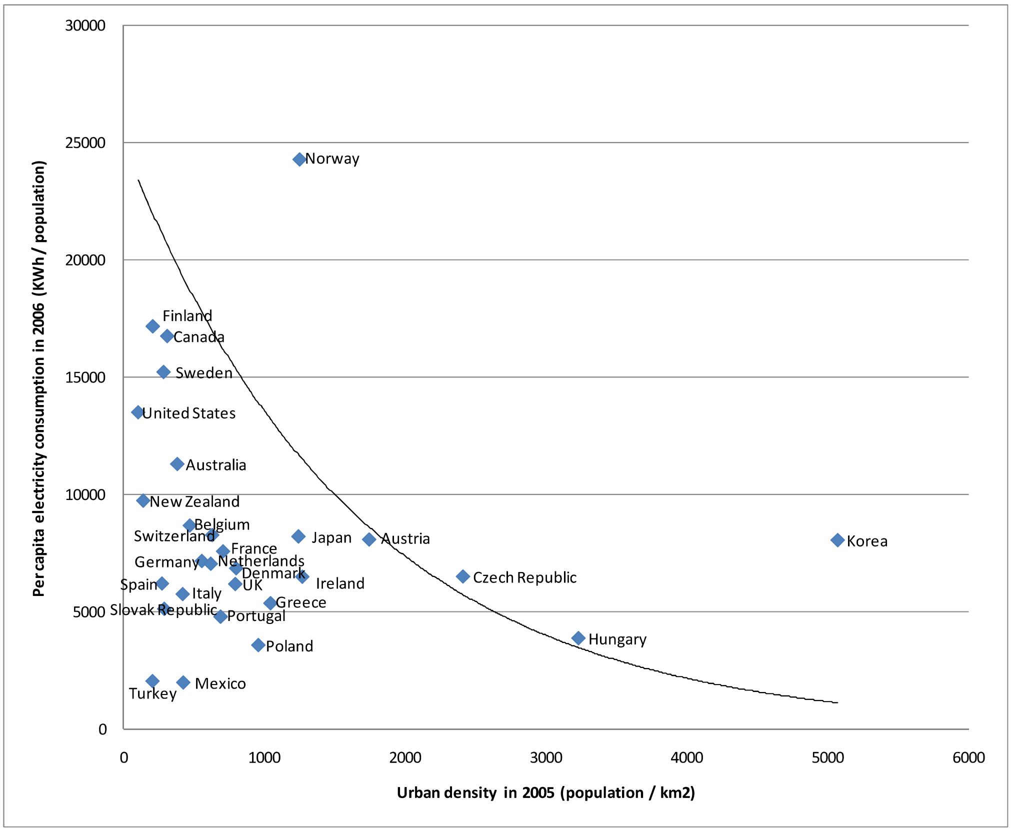


Figure 12.16. Same densities in three different layouts: a) high-rise towers; b) multi-story medium-rise; low-rise single-story homes (Source: Vicky Cheng, 2005).

12.4.3 Compact urban form

Urban form is part of the explanation for the differences between Europe's comprehensive and well-patronized public transportation systems (Goodwin et al., 1991) and the limited, poorly patronized systems typical in North America and Australia (Kenworthy and Laube, 1999) and sub-Saharan Africa (Dewar and Todeschini, 2004). An additional consequence of more expansive urban forms is that utility lines are considerably longer than in more compact forms, thereby significantly increasing direct and embodied energy use and thus greenhouse gas emissions.

Here the essential distinction is between low density and expansive urban forms versus higher-density and compact spatial forms. The term 'urban sprawl' is often used to describe urban development with any of the following characteristics: leapfrog patterns of development, commercial strips, low density, separated land uses, automobile dominance, and a minimum of public open space (Gilham, 2007). However, it is important to note that there is no universally accepted definition or metric for urban sprawl. The key variable between these forms is travel patterns, and a primary indicator of greenhouse gas emissions is vehicle miles travelled (VMT) (Newman and Kenworthy, 1989).



Notes:
Urban density is calculated on the basis of PU areas.
Iceland and Luxemburg were not included in the sample as the OECD Regional Database identifies no predominantly urban (PU) regions in those countries.

Figure 12.17. Population density and electricity consumption. Source: (Kamal-Chaoui and Robert, 2009)

It has been found that VMT decreases with increasing density while public transportation use and efficiency increases with density (Rickwood et al., 2008). While there is widespread agreement about the correlation between density and VMT, there is far less agreement about causality (Badoe and Miller, 2000; Rodriguez et al., 2006). A study of travel distances in the US has found a range of elasticities of travel distance around factors such as street design, diversity, distance to transit, and density (Ewing and Cervero, 2010b). It is difficult to establish causality because transport and land use are dependent and complexly interrelated. High population densities and compact urban design are required to support mass transit alternatives to the automobile.

12.4.4 Mixed land uses

There is consensus in the literature that mixed land use is a necessary condition for clustering of economic activity and promoting walking and non-motorized travel (Parmera et al, 2008). Mixed land use tends to reduce aggregate amounts of vehicular movement and associated vehicular-generated greenhouse gas emissions (Lipper et al., 2010). Mixed land use also enables walking more than settlements characterized by high degrees of mono-functionality. By promoting walking and cycling, mixed land use has a beneficial impact on urban citizen health and well-being (Heath et al., 2006). There is no evidence of negative externalities of mixed use in the literature.

Green areas can make cities more attractive to live in (particularly important for promoting more dense cities) and may promote walking and bicycling. Urban greenscapes can provide biomass for building heat and thereby reduce the demand for fossil fuels, although this potential is limited. The potential for carbon sequestration in green areas within cities is usually small and limited to the growth phase of plants. Vegetation can reduce the reflection of sunlight and can play a role in reducing heat island. However, the concept of mixed-use is ambiguous, both in terms of theory and practice (Rowley, 1996; Hoppenbrouwer and Louw, 2005). It must be defined according to the appropriate spatial scale in order take full advantage as a policy tool for climate change mitigation (Bourdic et al., 2012).

City-scale mixed land use: Mixed use on the city scale often dedicating a large areas of a settlement to a single and specific use: offices in business districts, shops and malls in commercial areas, and housing in residential areas. This style of city-level zoning is common in North American cities and in many new urban developments in Asia, notably China. Single-use zoning tends to leads to higher travel distances, especially from workplaces to housing and from shops to housing, and thus encourages automobile use.

Neighborhood-scale mixed use: Mixed use on the neighborhood scale rests upon a "smart" mix of residential buildings, offices, shops, and urban amenities (Bourdic et al., 2012). It has beneficial impacts on transportation patterns by decreasing average travel distances (McCormack et al., 2001). Non-motorized commuting such as cycling and walking and the presence or absence of neighborhood shops can be even more important than urban density (Cervero, 1996). The presence of shops and workplaces is also associated both with relatively low vehicle ownership rates and relatively shorter commuting distances among residents of mixed-use neighborhoods (Cervero and Duncan, 2008). Mixed use development at the neighborhood scale has a positive impact on transportation patterns, and contributes to climate change mitigation.

Block scale mixed use: At the block and building scale, mixed use consists of developing small-scale business spaces for offices, workshops, and studios on the ground floor of residential blocks and home-working premises. This option increases the area's vitality and is a way of achieving an visually interesting urban environment (Hoppenbrouwer and Louw, 2005). A co-benefit of block-scale mixed use is that energy flows may be reused and recycled (Larsson et al., 2011). The presence of different types of buildings within a given urban block leads to a variety of energy load demands: water demand and heating and cooling energy loads are different for housing, offices and shops. A diversity of loads allows the implementation of synergy approaches based on exchange, recycling and reuse of energy and material flows between different uses (Larsson et al., 2011).

12.4.5 High connectivity

Connectivity refers to the design of intersections, street density, and the density of four-way intersections. High connectivity and finer grain systems, characterized by smaller blocks which enable frequent changes in direction, are necessary conditions to encourage and enable non-motorized travel behaviours and promote walking. Settlements with a fine-scaled urban fabric (where buildings are close together, block dimensions are small, and streets are narrow) promote walking more than coarse-grained settlements. There are a number of reasons for this: walking distances tend to be shorter, and the system of small blocks enables the pedestrian to change direction easily, a factor which promotes convenience. Related to this is the quality of the public spatial environment. Walkable neighborhoods foster the use of non-motorized travel and public transport modes (Gehl, 2010). Impacts of high connectivity on material use and corresponding embedded emissions are still poorly understood.

12.4.6 High accessibility

Accessibility is a function of travel time, and distance between destination and origin. By creating low daily commuting distance and travel time, highly accessible communities enable multiple modes of transportation and less travel-related energy and emissions. Moreover, material demand and corresponding embedded emissions are likely to be lower compared to urban sprawl due to increased density.

12.4.7 Integrating multiple transport modes

Provision of multimodal transportation infrastructure and deployment of fuel efficient carriers creates a win-win scenario for implementation of mitigation, adaptation and local sustainable development measures.

Table 12.9: Urban mitigation opportunities for spatial planning and systemic integration and their impacts on GHG emissions in different sectors within and outside the city's system boundaries. Assumptions reflect an average city that imports construction materials, fuels, electricity, and food from outside its borders. Color code: green – positive savings, red – negative savings.

Emissions	1 Transport	2 Buildings	3 Industry	4 Energy Supply	5 Agric / Forestry		6 Waste Mgt (incl. wastewater mgt)	Co-ben.	Risks
Drivers	- km travelled - transport mode - fuel efficiency - C intensity of fuel	- Floor area - Energy use per FA - C intensity of energy	- Materials demand - Recycling - Energy efficiency	- Transport fuel production - Building fuel production - Electricity production - C intensity of energy production	- Demand for wood - C sequestration in forests & buildings		- Urban mining / waste separation - CH4 landfills - CO2 Waste incineration - Energy per waste - CH4 and N2O wastewater treatment		
Urban mitigation opport.	Inside	Inside	Inside & Outside	Inside & Outside	Inside	Outside	Inside & Outside		
1. Density	km traveled transport mode	Energy use FA	Material	T fuel			Urban mining		Urban heat islands
2. Land extent (form)	km traveled transport mode		Material	T fuel					
3. Land uses	transport mode			T fuel	C seq.			Attractiveness	
4. Connectivity (grain design)	transport mode			T fuel					
5. Regional accessibility	transport mode		Material	T fuel					
6. Transit	transport mode Fuel efficiency C intensity		Material	T fuel					
7. Buildings		Energy FA C seq.	Material	B fuel B electricity I fuel I electricity					
8. Energy		C intensity	Material	B fuel B electricity		Wood demand			
9. Waste	km traveled		Recycling				CH4 landfills CH4, N2O WWT	Save res & waste	
10. Water			Water, Material	Wastewater cooling					
11. Food	km traveled		Food process	Food processing		Animal Manure			

12.4.8 Systems integration of energy and material flows

Due to the socio-metabolic linkages between the individual sectors, mitigation measures in a specific sector usually affect the material and energy flows in other sectors, which may result in positive or negative feedbacks for emissions throughout the system. These consequences may occur within or outside the urban system boundaries. Table 12.9 illustrates eleven intervention areas or urban mitigation opportunities (rows) and their potential impacts on emissions in different sectors (columns), within and outside the city's boundaries. The mitigation opportunities include spatial planning interventions (1-6) and systemic interventions (7-11). It is assumed that the city imports the vast majority of construction materials, fuels, electricity, and food from hinterlands. The list of mitigation opportunities is not exhaustive and does not reflect the significant differences among cities with respect to geographical and socio-economic boundary conditions, including the state of the existing built environment stocks.

Systemic integration of energy, waste, water, and food in human settlements can yield significant energy and emissions reductions. For future infrastructure, reducing the CCE of infrastructures can be identified by employing a Kaya-like decomposition for the emissions, F (Müller et al., 2013):

$$F = P * \frac{S}{P} * \frac{M}{S} * \frac{F}{M}$$

Assuming that the population (P) is given and the service level per capita (S/P) can be defined using industrialized countries as a reference, the CCE of future infrastructures can be reduced by two approaches: (i) cutting the emission intensity of materials (F/M) and (ii) lessening the material stock per service unit (M/S). Options for reducing the emission intensity of materials are discussed widely in the literature and are described in detail in Chapter 10.

Options for reducing the material stock per service unit, in contrast, have received little attention so far. They can be divided into two approaches: studies of individual structures and studies of entire urban systems. Studies of individual structures, ranging from alternative forming of parts to product design, are a large, yet underexplored potential (Allwood et al., 2011). For example, low-rise medium density houses in Australia are less energy-intensive in construction than detached houses due to savings in shared walls, economies of scale, and surface area to volume ratio. However, for buildings higher than three stories, the embodied energy per floor area rises due to exponentially increasing structural demands (Treloar et al., 2001; Rickwood et al., 2008).

On a whole urban systems scale, saving effects on the product level can be reinforced or undone due to spatial constraints. Since the total CCE of built environment stocks among industrialized countries is fairly similar (Figure 12.18B), the overall potential for decoupling may be limited despite the large differences among individual structures. For example, studies of infrastructures such as roads (Ingram and Liu, 1997) and urban water and wastewater networks (Pauliuk et al., 2013) suggest that network length and material stocks tend to decline with increasing urban density (Figure 12.18). Furthermore, denser urban areas provide incentives for a modal shift in transport in the form of public transport or cycling, which reduces vehicle ownership and related material stocks and emissions (Newman and Kenworthy, 1999b; Kenworthy, 2006). However, denser urban areas have limited options for using emissions-saving building construction materials. There is a significant gap in design principles that take into account the scaling effects of individual structures, embodied emissions, and local conditions.

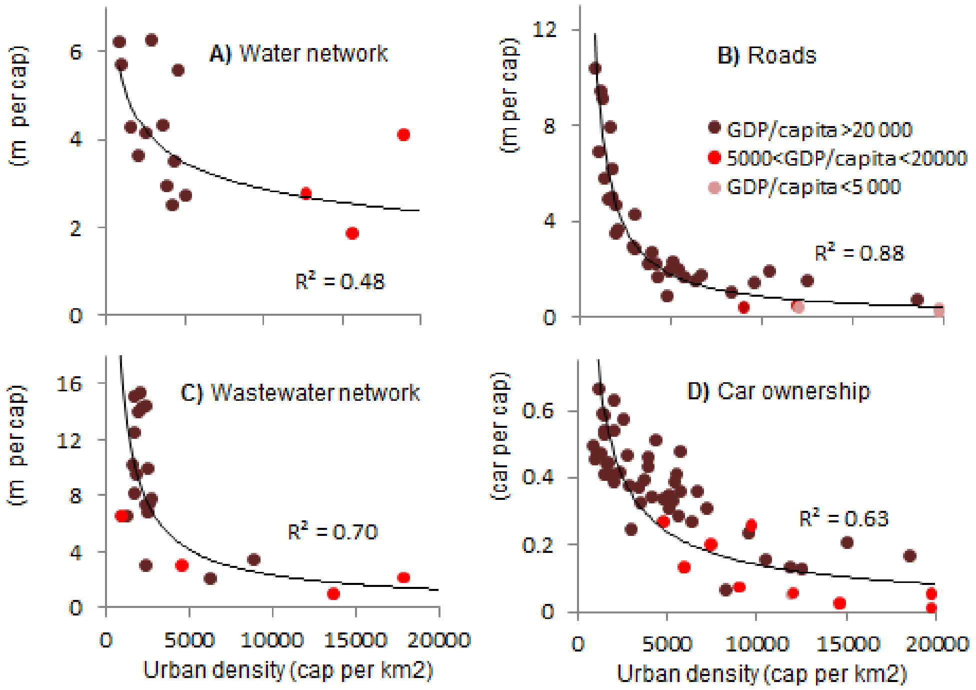


Figure 12.18. Impact of urban density and GDP (PPP) on network length and vehicle ownership: (A) water network, (B) wastewater network, (C) road network, (D) car ownership. Cities with higher density tend to have lower per-capita network length and vehicle ownership, indicating potentially smaller per-capita stocks and related CCE (Müller et al., 2013).

12.4.9 Energy

Municipal energy utilities can use efficient local electricity, and heat generating plants and renewable energy sources such as solar and wind. Interlinking renewable resources through a local grid may assist a city to become a power supplier (Vettorato et al., 2011). Integrated planning, including energy and water systems, provides additional mitigation potentials (Piguet et al., 2011). For example, Bataille et al. (2009) reported that an integrated community energy system could result in over 43% emission reductions in Vancouver. Hara et al. (Hara et al., 2001) reported an 11% CO2 reduction potential by combining solar power generation for residential buildings, waste heat energy, and co-generation for commercial buildings. To use solar energy more efficiently, rooftops in cities could be optimized for solar energy collectors, and building height and spacing could be optimized to maximize passive solar heating and cooling (Scartezzini et al., 2002). Despite many opportunities and scattered small-scale case studies, the share of energy that renewable sources can provide in large and dense cities is poorly understood and depends largely on the climatic and geographic conditions as well as the settlement structure.

"Smart Grid" technology has been used to introduce renewable electricity and reduce electricity consumption and utility peak in cities. This technology utilizes advanced sensor technologies throughout electricity infrastructures for two-way communications and demand response programs (Willrich, 2009).

12.4.10 Waste

Waste generation is directly proportional to urbanization, affluence, and population growth (Cointreau and Mundial, 2006; Bogner et al., 2008). Per capita waste generation rates are increasing both in developed and developing countries (OECD, 2009). Although, developing countries have low per capita waste generation rates relative to developed nations (Troschinetz and Mihelcic, 2009) their share in total global waste generation is high due to population size (OECD, 2009). Carbon intensity of waste collection and transportation in developing countries is about 16 kg of CO_2e/tonne of waste in contrast to developed countries at 7.2 kg of CO_2e/tonne of waste (Chen and Lin, 2008; Friedrich and Trois, 2011).

In addition, materials accumulated in infrastructure also turn into waste. They will not only represent a growing stock of mineable materials, but also future waste outflows. For these reasons, considering waste quantity, quality, and complexity (in terms of substance composition) at multiple spatial and temporal dimensions in terms of settlement material stock dynamics is essential for urban waste management (Lipper et al., 2010). Waste reduction strategies such as decoupling waste generation flows from economic factors can directly result in carbon emission reduction (Mazzanti and Zoboli, 2008). In addition, material recovery and recycling from waste, including urban mining, a long-term mitigation strategy oriented toward the consumption-waste interface through time (Baccini and Brunner, 2012). For example, in the US, recycling resulted in GHG emission savings of 183 million MT in 2006 (US EPA, 2009). Estimates for other regions vary widely, depending on the recycled material and downstream substitution in the use of the recycled material (Friedrich and Trois, 2011). Waste to energy reduces 1200 kg of CO_2e/ton of municipal solid waste combusted and can also replace 0.52 tons of coal per ton of municipal solid waste combusted (Nakata et al., 2011). However, maximum waste to energy potential is not directly proportional to GHG saving (Hanandeh and Zein, 2011). For additional information, including urban mining potential and waste processing and disposal methods that have implications on GHG emissions, see Chapter 10.

There is variability in these estimates which are attributable to differences in the definitions of waste streams and GHG accounting convention (Gentil et al., 2009), and assumptions in estimation models (Eriksson and Bisaillon, 2011). Complexity further increases while considering waste mix (Lacoste and Chalmin, 2006). For example, a wide range of GHG emissions from waste collection and transportation is attributable to fuel type, distance covered, and collection method (Eisted et al., 2009). Even consumption of diesel varies from 1.6 to 10.1 litre/ tonne of waste, and is found to be on the higher side for collection in areas with low population density and widely spaced residential units (Larsen et al., 2009). Similarly, GHG implications of composting depend upon whether compost produced from municipal solid waste can substitute for fertilizer production. For anaerobic digestion, GHG implications depend upon the extent to which solids in the digester are replaced with fertilizer and fossil fuel substitution for heating and lighting.

12.4.11 Water

Urban water systems produce GHG emissions in the form of CO_2, CH_4 and N_2O (Listowski et al., 2011). Open drains, polluted lakes and rivers, water storage in barrages/dams, and treatment methods in sewage treatment plants are main sources of direct GHG emissions. In addition, water infrastructure is material intensive and construction involves substantial indirect emissions (Venkatesh and Brattebø, 2011). Water-energy-carbon linkages in cities include: energy consumption for pumping, treatment, distribution, and heating water; thermo-electric energy production water consumption; and others (Table 12.10). Direct energy use by water utilities varies by city. Based on the evidence from Australia, California, and Canada, the energy intensity of the complete urban water cycle is in the range of 40-80 kWh/m^3 (Plappally and Lienhard V, 2012). Maximum energy consumption is found in the end use stage. The energy estimates are higher when they include: (i) energy consumed by transporting water from distant surface water sources, (ii) energy consumed by booster pumps at the household level in water distribution systems in developing countries, (iii) energy demand of decentralized waste water treatment plants in industries and institutions, (iv) energy consumed in forms other than electricity; (vi) 100% collection and treatment of wastewater in cities in developing countries; and (vii) embodied energy of materials.

Water usage in cities is typically lower than agricultural use. However, its socio-economic impact is high and the embodied energy and emissions in water infrastructure are usually substantial (CEC, 2005; LBL, 2011). The energy demand for water sourcing is increasing because surface water needs

Table 12.10: Energy implications of urban water cycle and mitigation options

Activity	Energy implications	Mitigation options
Sourcing	Surface water sources are getting distanced and groundwater sources are getting deeper (Kummu et al., 2011). Specific groundwater pumping energy use can go up to 0.006 kWh/m^{3}m and energy expended to supply surface water ranges between 0.002 to 0.007 kWh/m^3 km (Plappally and Lienhard V, 2012).	Energy intensity can be reduced by increasing the pump efficiency at regular intervals and monitoring pressure losses. (Thirwell et al. 2007) Rainwater harvesting checks decline in groundwater level and water conservation and recycling reduces the demand of energy for water sourcing.
Distribution	Distribution is the second highest energy consuming activity in the urban water cycle. Energy intensity for water distribution ranges between 0.05 to 0.44 kWh/m^3 (Venkatesh and Brattebø, 2011; Plappally and Lienhard V, 2012).	Water losses due to leakage are large in developing countries. Water loss due to leakage can be mitigated through demand and supply management (Fredrick et al., 2009). Other mitigation options include leak detection, pipeline pressure management, pipeline infrastructure rehabilitation at appropriate intervals, application of automated system control devices, and use of renewable energy for water pumping.
Water treatment	Energy intensity of conventional treatment processes range between 0.01 to 1.44 kWh/m^3 (Plappally and Lienhard V, 2012). The value depends on technology choice and desired quality. For example, energy intensity for the disinfection process using UV is 0.002 and using ozone is 0.18 kWh/m^3 (Plappally and Lienhard V, 2012).	Improving pump efficiency can reduce energy consumption by 3% to 6% in the treatment plant (Stillwell et al., 2010).
End use	End use activities consume up to 72% energy in the entire urban water cycle (Plappally and Lienhard V, 2012). End use processes often have the highest energy intensity of all the water-sector elements and deserve far greater attention (Rothausen and Conway, 2011).	The form of energy use can also influence the GHG emissions. Usage of roof top solar water heating systems and reduced hot water demand through energy-efficient water heaters, water-efficient domestic appliances (clothes washers, dishwashers), and plumbing fixtures can reduce energy consumption (Bakker et al., 2005).
Wastewater collection	Energy intensity varies between 0.003 to 0.81kWh/m^3 for wastewater pumping and collection (Venkatesh and Brattebø, 2011; Plappally and Lienhard V, 2012).	Where appropriate, on-site sanitation (decentralized treatment and recycling) can reduce wastewater (Fredrick et al., 2009).
Wastewater treatment	Energy consumption for treatment ranges between 0.09 to 4.04 kWh/m^3 depending upon the technology choice (Plappally and Lienhard V, 2012). For example, energy intensity is 0.18 to 0.42 kWh/m^3 for trickling filter, 0.33 to 0.60 kWh/m^3 for activated sludge process, and 0.1 to 1.5 kWh/m^3 for membrane bio-reactors (ibid).	Energy recovery and use of bio-gas can reduce the energy intensity of the treatment plant and off-site GHG emissions by 11-29% (Yerushalmi et al., 2009). Carbon intensity can be reduced further by using clean energy source such as wind energy and solar energy (Listowski et al., 2011)
Wastewater reuse	In Singapore, energy intensity for recycling wastewater for drinking purpose is found to range between 0.72 to 0.93 kWh/m^3. In Australia, large scale potable wastewater recycling using the R.O. process consumes energy in the range of 2.8 to 3.8 kWh/m^3 (Plappally and Lienhard V, 2012).	Urban green spaces can use recycled water, which reduces the treatment requirements for recycling water.

to be transported over longer distances or extracted from greater groundwater depth. For example, in Aguadulce, Spain, water is transported from a distance of over 700 km having energy intensity above 4 kWh/m^3 whereas in Perth, Australia, water is transported from a distance of 116 km requiring energy intensity of 0.21 kWh/m^3 (Plappally and Lienhard V, 2012). It is particularly important in regions where high population growth and urbanization have caused a water crisis, pitting the water use for urban activities against agricultural and environmental water needs.

12.4.12 Food

About 14% of global GHG emissions are attributable to agriculture, and between 17-32% when considering land conversion effects (Pelletier and Tyedmers, 2010). Urban settlements typically include a small share of agricultural area, but still depend largely on food imports from the immediate rural hinterland and beyond. In general, urban diets have become more water and carbon intensive because of increases in meat, dairy products and processed food consumption (Pimentel and Pimentel, 2003; Theun Vellinga et al., 2010; M.M. Mekonnen and A.Y. Hoekstra, 2010). While animal calories represent up to one third of total available calories in developed regions, emerging economies have increased animal consumption by up to five times between 1961 to 2007. This has lead to a global demand for animal products, which have already produced up to 50% of total land demand and land-use change during that same period (Steinfeld and Gerber, 2010; Kastner et al., 2012).

Urban food metabolism analyses are useful tools for accountability of production and consumption GHG emissions associated to urban diets (Delgado et al., 2010) Ramaswami et al, 2012). By taking into account inputs, stocks and outputs of the whole food system, urban food metabolism comprises all subsystems of production, supply, distribution, consumption, and generation/recycling of pollutants and waste. Preliminary indirect emissions (from “farm to table”) of only urban demand for meat, dairy, and chicken eggs, have been estimated to be 1.57 ton/ha/year for Buenos Aires; 0.72 ton/ha/year for Mexico City; and 1.04 ton/ha/year for Sao Paulo and Rio de Janeiro. Differences between cities are mainly due to differences in meat and dairy products consumption (Delgado, 2012).

There is consensus that optimizing urban food metabolisms and food waste in cities can be mitigation strategies. However, their overall impact on total emissions is unclear.

12.5 Spatial planning and climate change mitigation

12.5.1 Spatial and integrated planning

Spatial planning is a holistic approach to guide the development and investment in infrastructure and can include land use planning, regional planning, and environmental planning at different spatial scales (Wegener, 2001; Fischer-Kowalski et al., 2004; Yang et al., 2008; Hoornweg et al., 2011). There is general agreement that spatial planning can play an important role in reducing greenhouse gas emissions by influencing the structure, form, density, and infrastructure of a city (Carter and Fowler, 2008; Fields, 2009; Antrobus, 2011). This section assesses current knowledge on how spatial planning can contribute to climate change mitigation.

The underlying principle of integrated spatial planning is to coordinate land-use planning with other sectoral activities such as environmental policy, housing, and economic or regional development into a single framework (Eskelinen et al., 2000; Wong 2002). What differentiates an integrated spatial planning approach from individual sectoral approaches to climate change mitigation is that by coordinating multiple sectors, it is able to take advantage of solutions for a settlement as a whole that are not possible by individual sector policies alone. One estimate suggests that land-based mitigation is expected to contribute approximately 100 to 340 Gtc equivalents over the next century, or approximately 15-40% of total abatement (Rose et al., 2012).

Integrated planning of land-use and transport can lead to an increased use of alternative modes of transportation due to other factors such as regional accessibility, land use mix, connectivity, and transport system diversity (Litman, 2012). In addition to changing travel patterns and the built environment, increasing accessibility through land use mix and connectivity rather than transport sdfainfrastructure alone can have a positive effect on health through reducing vehicle-based pollutants but also by the materials utilized (Younger et al., 2008). Co-benefits may thus include cleaner air, preservation/restoration of ecological services, and improvement of personal health (Frank et al., 2004; Brown et al., 2008; Rodrigue et al., 2009; Marshall et al., 2009; Hankey and Marshall, 2010). In addition, density and mixed land use can also reduce – to some degree – the amount of land needed and the energy and material flows and stocks required for building and maintaining roads, parking facilities, and other related infrastructure. Spatial planning shows potential to enhance the capacity of new technologies to promote new, low-carbon urban form (Crawford and French, 2008). In contrast, a lack of integrated planning and a focus exclusively on infrastructure expansion can result in a decline in mobility with several unwanted societal impacts; for example, while infrastructure has quadrupled over the last 50 years for some megacities of developing countries, mobility has fallen by up to 50% (Moavenzadeh and Markow, 2007).

12.5.2 Planning strategies to attain and sustain low carbon human settlements

The implementation of various spatial densification and reconfiguration strategies is on-going in most developed and developing countries. For more effective implementation, key policy options and instruments need to be properly defined, ordered, adopted, and linked to national, regional, and local contexts (Figure 12.19).

A number of different spatial planning strategies, including policies and instruments, can help attain and sustain the characteristics of low carbon human settlements. Research conducted for UN-Habitat found that: “various strategies of land-use planning, including land use zoning, master-planning, urban densification, mixed use development, and urban design standards have been used in order to limit urban expansion, reduce the need to travel, and increase the energy efficiency of the urban built form” (UN Habitat, 2011) (UN Habitat 2011; also see UN Habitat 2009). Here we outline eight common and effective options currently utilized in many cities and regions.

12.5.3 Growth management

Fundamental to many spatial initiatives for rapidly growing human settlements is growth management (e.g., green belts, urban growth boundaries, urban containment policies), directly curbing low density and leapfrog development using zoning, land taxations and rent controls, financial and legal incentives, and land acquisitions/preservations (Pendall et al., 2006; Feiock et al., 2008; Lai et al., 2011). In response to periods of rapid urban growth, capitals of European and Asian countries (e.g., London, Stockholm, Tokyo, Seoul, Beijing and Bangkok) and progressive city-states in North America and Australia (e.g., Ottawa, Portland, Boulder, Minneapolis–Saint Paul, and Melbourne) adapted the idea of urban growth management under different policy names, such as “green belt”, “urban containment strategy”, and “urban growth boundary”. In many rapidly growing city-regions around the world, however, these land policy instruments remain under local legislations (or “jurisdictional units”), thereby limiting their full potential. Regional or even mega-region-wide institutional coordination and enforcement would be more effective at limiting or containing “sprawl” (McCabe, 2005; Mills et al., 2006; Zhao et al., 2009; Firman, 2009; Todes, 2012).

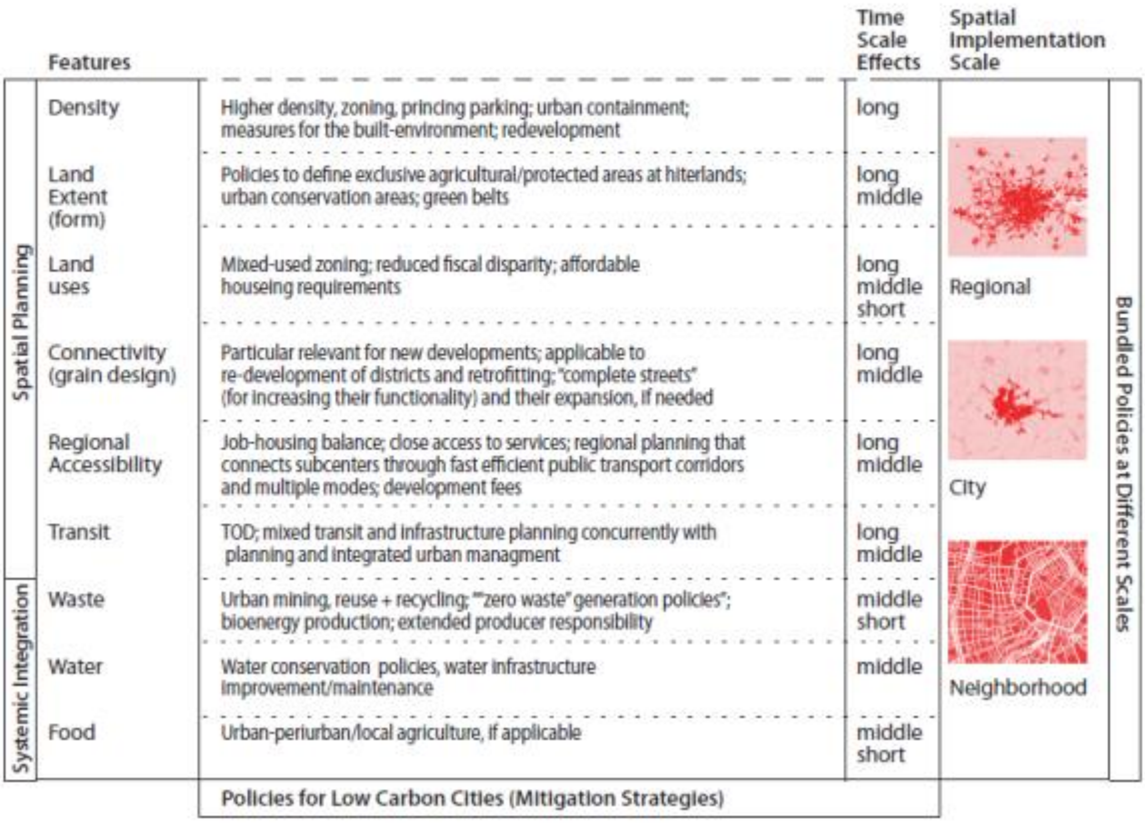


Figure 12.19. Mitigation strategies to achieve characteristics of low-carbon settlements

12.5.4 Regional planning and governance

Regional planning is indispensable in the establishment of long-term spatial visions that discourage the patchy expansion of cities across a number of local jurisdictions. Indeed, the spatial measures of rapidly growing cities in the United States (e.g., Los Angeles, Atlanta and Miami) have presented "edgeless" office location patterns over the past decade, due in large part to weak or unsuccessful intergovernmental response to the negative externalities of freeway paradigms (Lang, 2003; Lang et al., 2009). On the other hand, the concept of "polycentric" spatial development has been widely formulated and adopted in national and inter-municipal planning systems across northwest Europe, such as South East England, Paris Region, Central Belgium, Randstad, RhunRuhr, Rhine-Main, EMR Northern Switzerland, Greater Dublin and Stockholm Metropolitan Region (Salet and Thornley, 2007; Hall, 2009a; Rader Olsson and Cars, 2011).

Similar strategic efforts have recently been made by North American regional planners and planning institutes for the Northeast, Great Lakes, Southern California, Piedmont, Atlantic, Cascadia-Northwest, Arizona Sun Corridor, and Texas Triangle areas where population and employment are already concentrated (Dewar and Epstein, 2007). In the new polycentric mega-region strategies, multibillion-dollar investments in intercity transportation hubs (e.g., international hub airports and high-speed rail terminuses) play a pivotal role in enhancing high-density employment centers, accompanied by proactive land policies and property developments (Kasarda, 2000; Vega and Penne, 2008; Hall, 2009b; Freestone, 2009). The capacity of regional coordination seems even more critical to determine the spatial characteristics of both existing and emerging mega city-regions in Asia with over 10 million urban inhabitants (e.g., Tokyo, Delhi, Mumbai, Shanghai, Beijing, Osaka-Kobe, Jakarta, Guangzhou, Shenzhen, Wuhan and Bangkok), along with major infrastructure projects for growing intercity mobility (e.g., Beijing-Guangzhou-Shenzhen-Hong Kong High-Speed Railway, Beijing Capital International Airport) (Kasarda, 2006; United Nations, 2011b; Yang et al., 2011) (Zhao et al., 2011).

12.5.5 Public transit investments

Public transit investments are used to guide large development patterns and/or adapt regional travel behaviors around city-regions' strategic growth areas and heavily congested corridors. Since the 1990s, delivering costly rail projects (e.g., high-speed rail, commuter rail, mass rail transit and light rail transit systems) has become a popular approach to realizing sustainable urban development across relatively large-regions and/or high income cities in North American, European, and Asian countries, such as New York-Washington DC, Los Angeles-San Francisco, London, Amsterdam, Stockholm, Copenhagen, Zurich, Munich, Singapore, Tokyo, and Hong Kong (Cervero, 1998; Lam and Toan, 2006; Hickman and Hall, 2008; Cervero and Murakami, 2009; Todorovich et al., 2011; Guerra and Cervero, 2011). Nevertheless, long-term experiences and analyses of large cities in North America, Europe, and Japan show that the spatial impacts of public transit investments are localized typically in traditional downtowns (or central business districts) where land redevelopment policies, real estate markets, and existing built environments are transit-supportive (Cervero and Landis, 1997; Banister and Berechman, 2000; Giuliano, 2004; Handy, 2005). This empirical evidence suggests that substantial investments in traditional hub-and-spoke networks and fixed route services could not meet complex point-to-point flows and specific travel needs in low-density, automobile-dependent suburban and exurban markets (Urbitran Associates and National Research Council, 2006). Indeed, bus rapid transit (BRT) services have been more flexibly and affordably adapted in less populated areas and/or less wealthy cities across North America, South America, and Australia, such as Los Angeles, Miami, Sydney, Adelaide, Bogota, San Paulo and Curitiba (Cervero, 1998; Levinson et al., 2003; Hensher and Golob, 2008; Bocarejo et al., 2013).

12.5.6 Transit-oriented development

Transit-oriented development (TOD) centers are increasingly reflected on the spatial agenda of many regional and local governments, notably in rapidly growing city-regions in North America, Australia, and China, aiming to encourage public transit usage and non-motorized travel by creating short-distance, high-density, and well designed built environments at key nodes of the urban transit network against automobile-dependent suburban markets around suburban and exurban highway interchanges (Calthorpe, 1993; Cervero et al., 2004; Zhang, 2007; Curtis, 2008; Curtis et al., 2009). The installation of TOD design into city and regional contexts is not a monotonous or "cookie-cutter" modeling process. A range of TOD packages (e.g., urban downtown, urban neighborhood, suburban center, suburban neighborhood, commuter town center, and neighborhood transit zone) need to be demonstrated to increase the spatial match between site conditions, business advantages, and lifestyle preferences in already automobile-dependent American city-regions (Dittmar and Ohland, 2004). TOD redevelopment areas are not solely defined as local government agendas or urban design concepts but rather as complex and dynamic spatial interactions between public policies and private practices (Bertolini, 1996; Bertolini and Split, 1998; Reusser et al., 2008; Curtis et al., 2009).

Even more entrepreneurial "value capture" approaches have been seen in a few wealthy Asian cities (see [TSU: Reference missing]). Private or privatized mass railway corporations in Hong Kong, Greater Tokyo, and Osaka-Kobe proactively developed and have managed large-scale, high-density, and well-mixed property packages with pedestrian-friendly built environments to capture increased capital gains through development rights sales and land readjustment projects (Cervero, 1998; Curtis et al., 2009; Cervero and Murakami, 2009), whereas public transit agencies in many North American cities usually take more modest and passive action on transit-supportive property development projects through betterment tax, impact/connection fees, and tax incremental financing schemes (Cervero et al., 2004; Dittmar and Ohland, 2004).

12.5.7 Urban regeneration projects

Urban regeneration projects are one of the major spatial strategies being chosen by global cities (e.g., New York, London and Tokyo) and "newly industrialized economies" (NIEs) in Asia (e.g., Hong Kong, Singapore and Seoul), which are competing for transnational capital flows (headquarters of multinational corporations, foreign direct investments, value-added information and skilled labor force) (The Urban Task Force, 1999; Castells, 2000; Fainstein, 2001; Sassen, 2001; Han, 2005; Shimizu and Nishimura, 2007; Sorensen et al., 2009). The urban regeneration boom in recent years is largely finance-driven through public-private partnerships. City government agencies typically place target economic zones, development right sales, density bonuses with public space requirements, tax and legal incentives, and/or road pricing schemes along with transit capital reinvestments, while private developers apply real estate investment trusts (REITs) for infill/brownfield redevelopments and local enterprise associates designate business improvement districts (BIDs) for high-amenity and pedestrian-friendly built environment creations (Lloyd et al., 2003; Steel and Symes, 2005; Han, 2005; Ward, 2007; Jonas and McCarthy, 2009; Sorensen et al., 2009). While the entrepreneurial nature of local governments has generated substantial private capital gains and public revenue streams for major infrastructure projects, property-led densification and regeneration programs have raised general concerns about housing price escalation and social segregation, notably in large Chinese city-regions such as Beijing and Shanghai (Fainstein, 2001; Sassen, 2001; He and Wu, 2005; Lees, 2008; Shin, 2009; Talen, 2010; McDonnell et al., 2011; Dave, 2011).

12.5.8 Mixed income/affordable housing

The provision of affordable/mixed income housing is an essential component of nearly all spatial strategies to ensure the physical proximity and accessibility to regional/sub-regional employment centers (Aurand, 2010), while urban regeneration policies basically increase both commercial and residential property prices in cities' central areas, pushing lower-income households toward regions' peripheral areas, raising the spatial imbalance between employment and population, and stretching their commuting distances over the entire city-region. This spatial mismatch is not only in North American city-regions but also in Chinese city-regions (Wang et al., 2011; Zhou et al., 2012). In Shanghai, for instance, households resettled in peri-urban locations where affordable residential properties are physically less integrated with rail transit stations, local feeder bus services, and high-amenity built environments, lead to increased dependence on the private vehicle and/or acceptance of long commuting times (Cervero and Day, 2008; Day and Cervero, 2010).

12.5.9 Integrated transportation planning

Integrated transportation planning and policy make transit-oriented business/lifestyle practices possible and encourage more efficient employment/residential location choices by spatially arranging zone- or network-based road pricing schemes, parking space restrictions, region-wide fare integration, multimodal network connectivity, and local feeder/community circulation services to meet diverse development types and complex travel demands (National Research Council, 2003; Marsden, 2006; Loo, 2007; Weiner et al., 2008; Hidalgo, 2009; McDonnell et al., 2011; Condeço-Melhorado et al., 2011; Barter, 2011; Tirachini and Hensher, 2012; Sharaby and Shiftan, 2012; Shewmake, 2012). The world's most integrated transportation systems are in relatively small and wealthy cities, such as Singapore and Copenhagen, where the city-state's master plans are highly authoritative and the applications of advanced "smart" technologies for transportation demand management are geographically feasible/politically acceptable under the city-state's coordination and control (Cervero, 1998).

12.5.10 Elevated highway deconstruction and roadway reductions

The deconstruction of elevated highways and reduction of roadway lanes is an effective approach for urban place-making, reordering the spatial priority of urban business districts from the "mobility" of private vehicle drivers to the "accessibility" and "amenity" for public transit passengers and non-motorized travelers. When accompanied by transit infrastructure investments, transit-oriented developments and urban regeneration projects, and deconstructions are most effective for central cities in service- and knowledge-based or "deindustrializing" economies (e.g., New York, Boston, Portland and Milwaukee) (Cervero and Kang, 2011; Mohl, 2011). Empirical studies in downtown San Francisco (Central Freeway and Embarcadero Freeway Deconstruction Projects) and downtown

Seoul (Cheong Gye Cheon Project) suggest that the spatial reprioritization for urban accessibility and amenity increase both commercial and residential densities, and hence property prices, within walkable distances from highway deconstruction sites (Cervero et al., 2009; Kang and Cervero, 2009).

FAQ 12.3: What are the potential of human settlements to mitigate climate change, given their relatively small land area?

The spatial organization of human settlements is one of the major factors that determine energy use and emissions through the layout of streets and buildings, land use mix, accessibility to jobs and markets, infrastructure investments, and transportation corridors. Once in place, the basic spatial structures of human settlements are difficult to change. As a system, human settlements can increase the efficiency of infrastructure and energy use beyond what is possible with individual sectoral components by reducing material and energy flows.

12.6 Governance, institutions, and finance

The governance and institutional requirements that are most relevant to the need to achieve change in terms of the form, design, and connectivity of urban areas relate to spatial planning. The nature of spatial planning varies significantly nationally. In most national contexts, a framework for planning by sub-national (state and local) government is provided. Within these frameworks, different degrees of autonomy are afforded to municipal authorities. Furthermore, there are often divisions between land use planning (which is often organized hierarchically) where municipalities have a remit for the zoning and control of land within their jurisdiction, and transportation planning (which is either centrally organized or done in cross-cutting manner) in which municipal responsibilities are often more limited. Nonetheless, spatial planning is regarded as one area where municipal authorities usually have some formal powers and competencies that are of relevance to addressing GHG emissions.

12.6.1 Multi-level jurisdictional and integrated governance

The urban governance of land use and transport planning does not however rest solely with municipal authorities or with other levels of government. Increasingly, private sector developers are creating their own strategies to govern the nature of urban development that exceed codes and established standards. These strategies can relate both to the physical infrastructure being developed (e.g. the energy rating of housing on a particular development) or take the form of requirements or guides for those who will occupy new or refurbished developments (e.g., age limits, types of home appliance that can be used, energy contracts, education about how to reduce GHG emissions). Non-governmental organizations such as industry groups have also become important in shaping urban development, particularly in terms of regeneration and the refurbishment or retrofitting of existing buildings. This is the case, for example, in terms of community-based organizations in informal settlements, as well as in the redevelopment of brownfield sites in Europe and North America.

Taken together, these points suggest that the governance and institutional arrangements required to move human settlements towards the principles of low carbon development would include the following:

- An enabling multilevel governance context
- Spatial planning competencies in land use and transportation planning
- Institutional arrangements to integrate mitigation goals with existing urban agendas

- Modes of governance that realize municipal competency in terms of low carbon design standards
- Significant roles for private and non-governmental sectors

There are however significant challenges in realizing these ambitions. Multilevel governance systems often contain conflicting signals about the nature and purpose of land use and transport planning, due to the different drivers upon the planning system and the multiple goals it is required to meet (Bulkeley and Betsill, 2003, 2005; Gore, 2009). Even where there is a clear policy goal and where competencies for municipal planning exist, realizing these ambitions in practice can be challenging due to: 1) the historically embedded nature of existing urban forms; 2) the obdurate nature of infrastructure, such that it persists over long time frames and can be difficult to retrofit or reconfigure for new purposes (Hommels, 2005); 3) conflicts of interest, within and beyond the municipality (Bulkeley and Betsill, 2005); 4) long-standing professional and political assumptions about what constitutes “good” planning (Wilson and Piper 2010: 171); and 5) overt challenges to social norms about what constitutes “normal” housing and the “good life”(Gore, 2009).

Municipal authorities have led urban climate change policy responses within a context of multilevel governance (Bulkeley and Betsill, 2005; Gustavsson et al., 2009). Often in the absence of formal authority or specific competencies, municipalities have used their self-governing and enabling modes of governance to develop and implement climate policy (Bulkeley and Kern, 2006). This has been promoted by the self-organization of municipalities in transnational and national networks (Granberg and Elander, 2007; Holgate, 2007; Romero Lankao, 2007). These approaches, coupled with the nature of available funding and growing interest in the opportunities of addressing climate change in private and third sector organizations, have led to a new wave of strategic interest in governing climate change in cities and an important role for partnerships and project-based or ‘experimental’ forms of urban response (Castán Broto and Bulkeley; While et al., 2010; Hodson and Marvin, 2010; Bulkeley and Schroeder, 2012). In short, ‘horizontal’ forms of multi-level governance through networks and partnerships have been critical in producing urban climate change policy. In contrast, there is more limited evidence that ‘vertical’ multi-level governance (in the form of regional, national, and international agencies) has been explicitly engaged in promoting urban responses but rather that this has created the ‘permissive’ or ‘restrictive’ context within which urban responses have developed (Betsill and Bulkeley, 2006).

There is strong evidence that addressing climate change has become part of the policy landscape in many cities and that municipal authorities have been able to reduce their own GHG emissions (Wheeler, 2008; Krause, 2011a; b). There is more limited evidence that urban climate change policy has achieved wider mitigation goals in terms of reducing GHG emissions at the urban scale, creating new logics and practices for urban development that realize climate change objectives alongside other urban goals, and achieving widespread ‘transitions’ to low carbon urban development (Hodson and Marvin, 2010; Rosenzweig et al., 2011). Lessons from urban case-studies show that a wide variety of approaches and measures can achieve policy goals but that a significant challenge remains in ‘scaling up’ and ‘mainstreaming’ these approaches.

Where success has been forthcoming, critical factors include the competencies and mandate of municipalities, financial resources, individual champions, political opportunities, and the realization of co-benefits (Betsill and Bulkeley, 2007). Likewise, institutional, political-economic, and infrastructural factors can explain the challenges that have been encountered in realizing policy ambitions (Bulkeley, H, 2010, 2012).

As the urban climate agenda gathers pace, an important challenge remains in terms of addressing the different capacities and responsibilities of urban communities to mitigate climate change. There has been limited engagement with what ‘common but differentiated’ responsibilities for addressing climate change means at the urban scale, and with the implications for how urban goals for climate change should be differentiated between and within cities. There is an important role for the international community and national governments in showing leadership with cities in establishing appropriate goals and mandates for action across highly uneven urban landscapes.

12.6.2 Institutional opportunities and barriers

Broadly speaking, *institutional* factors can be regarded as those that shape the capacity of urban institutions – both formal organizations, and more informal systems, codes and rules that guide social action – to respond to climate change. These factors include issues of knowledge, financial resources, and the ways in which responsibilities for action are allocated and shared between different organizations. In terms of knowledge, the lack of expert capacity at the local level as well as limited access to data at the appropriate scale have been regarded as significant barriers (Allman, L et al., 2004; Lebel et al., 2007; Sugiyama and Takeuchi, 2008).

Where action has been forthcoming at the municipal scale, this has often reflected the ability for a municipality to access dedicated (and often short-term) funding, including from national and international agencies and through the establishment of dedicated financial mechanisms within the city council to reinvest savings from energy efficiency programs. The resulting landscape of access to knowledge and finance has been highly uneven, and is often regarded as a critical factor shaping urban climate policy (Jollands, N, 2008; Sugiyama and Takeuchi, 2008; Setzer, J, 2009; Pitt, 2010). Equally important have been issues about the 'fit' between urban jurisdictions and the scale of the processes through which GHG emissions are produced, for example commuting in a metro area, and the cross-sectoral nature of climate change as an issue on municipal agendas (Schreurs, 2008). Given these challenges, vertical and horizontal forms of multilevel governance have been regarded as critical in promoting or constraining collaboration and in providing both concrete resource and a politically benign context within which to undertake municipal policy (Betsill and Bulkeley, 2007; Granberg and Elander, 2007; Holgate, 2007; Romero Lankao, 2007; Betsill and Rabe, B.G., 2009).

Frequently, the prescription given for overcoming such institutional barriers is to generate more capacity through the development of more knowledge, the provision of more resources, the creation of new institutions, the enhancement of 'good' governance, or through the ceding more autonomy to municipalities (Allman, L et al., 2004; Corfee-Morlot, J et al., 2009). The political factors that shape urban responses to climate change mitigation can be broadly considered in terms of issues of leadership, of opportunity, of co-benefits and of broader processes of political economy. The presence of policy entrepreneurs or political leaders has been found to be a critical driver of municipal responses, but in Durban, Mexico City, and São Paulo, their effectiveness was found to be constrained by the wider contexts within which they operate (Romero Lankao, 2007; Setzer, J, 2009; Aylett, A, 2010). Windows of opportunity in the urban context such as large-scale redevelopment projects, conferences, sporting events or disasters –can function as a means through which such barriers can be overcome.

Most fundamentally, the political challenges of addressing climate change in the city stem from the ways in which the issue is regarded with respect to other key urban agendas. Where action has been forthcoming this has been found to be due to the ability to 'reframe' or 'localize' climate change with respect to the co-benefits that could be realized (Betsill, M, 2001). For example, in Canada, "actions to reduce GHG emissions are also deeply connected to other goals and co-benefits such as human health improvements through improved air quality, cost savings, adaptability to real or potential vulnerabilities due to climate change, and overall improvements in short, medium and long-term urban sustainability" (Gore, 2009). 2009). Other studies suggest that is this process of reframing, 'localizing' or 'issue bundling' (Koehen, P, 2008) that has been effective in mobilizing local action on climate change in cities in the global south, and that this will remain an important aspect of building local capacity to act (Puppim de Oliveira, 2009).

12.6.3 Financing urban mitigation opportunities and barriers

Formulating and implementing plans for urban mitigation is predicated on the concerted effort of various level of governments which govern climate change related policies and objectives, a number of social actors, starting with citizens and communities and their associations and private sector organizations. A key need for such efforts, the financing of urban mitigation, can be drawn from a variety of resources some of which could be already devoted to urban development (Table 12.11). Local fiscal policies related to land-use, property and transportation investments are key tools which can be brought to bear by governments at various levels. In many industrialized countries, national and supra-national policies and programs have provided cities with the additional financing and facilitations for urban mitigation. Where the national commitment is lacking, state and municipal governments influence the mitigation initiative at the city scale. Cities in emerging economies are also increasingly engaging in GHG mitigation, but they often rely on international sources of funding to implement urban mitigation initiatives.

GHG abatement is generally pursued as part of the urban development efforts required to improve access to infrastructure and services in the fast-growing cities of developing countries, and to increase the livability of largely built-out cities in industrialized countries. Incorporating mitigation into urban development has important financial implications, as many of the existing or planned urban investments can be accompanied by requirements to meet certain carbon mitigation standards (OECD 2010). As decentralization has progressed worldwide (the average share of sub-national expenditure in OECD countries reached 33 percent in 2005), regional and local governments increasingly manage significant resources. Urban infrastructure investment financing comes from a variety of sources, including direct central government budgetary investments, intergovernmental transfers to city and provincial governments, revenues raised by city and provincial governments, the private sector or public-private partnerships, resources drawn from the capital markets via municipal bonds or financial intermediaries, risk management instruments, and carbon financing. Such sources provide opportunities for urban GHG mitigation initiatives (OECD 2010) but access to these financial resources varies from one place to another.

Table 12.11: Primary sources of financing for urban climate change mitigation

Budgetary allocations	**Municipal revenues**	**Firms and households**	**Development aid**
• Supranational grants (e.g. EU) • Federal or central Govt. budgetary allocations • Transfers to state or provincial Govt. • Capital markets for loans and bonds	• Earmarked property taxes • Land-value capture taxes • Congestion and parking charges • Salary surcharges for transportation • Municipal bonds	• Self-financed investments • Public-private partnerships • Cap-and-trade programs • Incentivized utility consumer loans • Carbon financing	• Global Environment Facility • Clean Development Mechanism, Joint Implementation • Climate Technology Fund, other Funds • Multilateral Development Banks

Local fiscal policy itself can restrict mitigation efforts. When local budgets rely on property taxes or other taxes imposed on new development, there is a fiscal incentive to expand into rural areas or sprawl instead of pursuing more compact city strategies (Ladd, 1998; Song, and Zenou, 2006). Metropolitan transportation policies and taxes also affect urban carbon emissions. Congestion charges reduce GHG emissions from transport up to 19.5 % in London, where proceeds are used to finance public transport, thus combining global and local benefits very effectively (Beevers and Carslaw, 2005). Parking charges have led to a 12% decrease of vehicle miles of commuters in US cities, a 20% reduction in single car trips in Ottawa and a 38% increase of carpooling in Portland (OECD, 2011).

12.6.4 Land value capture and land governance

Fiscal crises along with public investment, urban development, and environmental policy challenges in both developed and developing counties have sparked interest in innovative financial instruments to affect spatial development, including a variety of land-based techniques (Peterson, 2009). One of these key financial/economic mechanisms is land value capture. Land value capture consists of financing the construction of new transit infrastructures by the profits generated by the land value price increase associated with the presence of the new infrastructure (Dewees, 1976; Benjamin and Sirmans, 1996; Batt, 2001; Fensham and Gleeson, 2003; Smith and Gihring, 2006). Also called windfall recapture, it is a local financing option by recouping a portion or all of public infrastructure costs from private land betterments under the "beneficiary" principle. In contrast, value compensation, or wipeout mitigation, is commonly viewed as a policy tool to alleviate private land worsements—the deterioration in the value or usefulness of a piece of real property—resulting from public regulatory activities (Callies, 1979)(Hagmand and Misczynski, 1978). Classic concepts in planning, economics and law have been proven to be effective spatial strategies in contemporary contexts: urban growth management and regional planning/governance, public transit investment and transit-oriented development, and urban regeneration and affordable housing projects (Ingram and Hong, 2012).

Most studies of value capture financing for transit focus on U.S. cities, where low density development and auto-dependency predominate, but studies have begun to emerge from developing countries, where denser cities and a more even modal split can be found (Cervero et al., 2004). Under both capitalistic and socialistic landholding systems, there are various ways to implement the idea of value capture, including: land and property taxes, special assessment or business improvement districts, tax incremental financing, development impact fees, public land leasing and development right sales, land readjustment programs, joint developments and cost/benefit sharing, connection fees), most typically for public transit projects (Smith, J and Gihring, TA, 2006; Enoch et al., 2005; Bahl and Linn, 1998; Landis et al., 1991; Johnson and Hoel, 1985). There is much evidence that public transit investments often increase land values around new and existing stations (Debrezion et al., 2007; Du and Mulley, 2006)(Rodríguez, 2009).

The two most successful land value captures are Tokyo and Hong Kong metro systems. Tokyo has been the world's largest value capture process. The private railway corporations have constructed new towns around railway stations throughout the suburbs of Tokyo, exploiting the land-value gains in and around railway stations conferred by improved accessibility. This approach operated by a mix of public, private, and quasi-private entities, is efficient (Cervero, 2008). Hong Kong is an extreme case of the value capture application for sustainable transit financing and urban development. In Hong Kong, the metro system "earns unsubsidized fare revenue sufficient to cover all costs, including depreciation plus operating profit margin" thanks to value capture (Meakin, 1990).

(Cervero and Murakami, 2010) show that its entrepreneurial approach to public transit investments along with well-integrated property development packages generate accessibility, amenity, and agglomeration benefits and generates property price increases/substantial revenue streams for public financing. From an equity perspective, a high-density city, depending heavily upon land-based public-private financing, faces issues of real estate speculation and housing affordability. Ribeck (2004) and Gihring (1999) finds that increasing taxes on land values discourages speculative activities and urban sprawl, whereas decreasing taxes on building values reduces the costs of supplying commercial and residential space. Thus, a value-capture, split rate tax can help integrate market incentives with policy objectives: sustainable transit financing, affordable housing, and environmental protection.

The net impacts of land/property taxation policies on urban sprawl are still arguable, especially in the context of U.S. city expansions. Brueckner (2000) points out that the infrastructure-related tax charged on new homeowners is less than the actual infrastructure costs generated by them; however, the U.S. land-based financing distortion (e.g., inappropriate property tax on urban accessibility and amenity) tends to depress the density of urban land development and the level of urban capital improvements provided by private developers.

Bruckner and Kim (2003) further suggest that the property tax policies at the state and local levels boost the spatial expansion of U.S. city-regions where substitution between housing and other goods is low. On the other hand, Song and Zenou (2006) find that city size decreases by 0.4% if the property tax increases by 1% by controlling population, income, agricultural rent, and transportation expenditure variables across 448 U.S. urbanized areas. According to the empirical results, local property tax can incentivize urban sprawl reduction under some transportation and land market conditions. The reform of land/property taxation policies for sustainable infrastructure financing and growth management is of particular importance in China. It has been argued that the current development incentives in Chinese city-regions have generated government revenues to large-scale infrastructure projects, provided public goods, and improved land use efficiency in urbanized areas (Lichtenberg and Ding, 2009).

Box 12.1: Low-carbon development opportunities and challenges in LDCs

[TSU COMMENT TO REVIEWERS: Boxes highlighting further LDC-specific issues are included in other chapters of the report (see chapter sections 1.3.1, 2.1, 6.3.6.6, 7.9.1, 8.9.3, 9.3.2, 10.3.2, 11.7, 16.8) and a similar box may be added to the Final Draft of chapters, where there is none in the current Second Order Draft. In addition to general comments regarding quality, reviewers are encouraged to comment on the complementary of individual boxes on LDC issues as well as on their comprehensiveness, if considered as a whole.]

GHG emissions data and strategies for mitigation in developing countries have largely been limited to large cities such as Lagos, Cairo, Dhaka, Johannesburg and Cape Town. The underlying demographic transitions in LDCs are directly related to expansion of infrastructure, housing, and transportation and likely to influence future emissions. Currently, no developing countries have strategies and plans for low carbon growth at either national and city levels. Furthermore, few developing country cities have completed GHG inventories. This makes it particularly challenging for benchmarking and formulation of strategies for emissions reduction. Nearly all developing country cities will experience high rates of population growth coupled with high rates of infrastructure development in the next twenty years. These two trends will most likely raise city emissions. Aggregated nationally and globally, this has potential to increase global emissions.

The enormous mitigation challenges in developing country cities also present numerous opportunities. More than half of the urban areas expected to be in place in developing countries by 2030 have yet to be built. There are also many options for technology transfer and development of low-carbon infrastructure, off-grid energy systems and decentralized systems for water-sewerage-energy. ‘Low-hanging’ fruit transportation options have been piloted in South American and Asian developing country cities. From non-motorized transport, Bus Rapid Transit to hybrid low-carbon transportation systems of different modes, developing country cities have the opportunity to leapfrog the carbon-intensive infrastructure deficit through implementing strategies for reduced emissions (Rodríguez and Mojica, 2009).

With respect to material flows, especially biomass and nutrients, there are numerous options for recycling and reducing material and energy flows. In many developing country cities, spatial planning can be significantly strengthened in order to utilize urban form as a potential mitigation strategy. However, many developing country cities, especially in Africa, planning institutions are weak or non-existent, thereby further creating an opportunity for action.

Many of the strategies identified in this chapter may not apply to cities or settlements with low levels of governance or weak institutions. Moreover, a major focus for developing country cities is to address persistent poverty and development challenges. Yet, some mitigation benefits that can be linked to desired development pathways. For example, for cities where most of the buildings and infrastructure has yet to be developed, there are opportunities to align development and mitigation strategies. One of the main challenges to formulating low-carbon policies in low developing country cities is governance. Reconfiguring governance systems for climate change through structures, institutional agency and financing remain a challenge that is likely to affect the entry points for low-carbon policies.

12.7 Urban climate mitigation: Experiences and opportunities

12.7.1 City climate action plans

Since the IPCC 4th Assessment Report, thousands of cities around the world have implemented or are developing climate change mitigation plans (Table 12.12). The numbers of cities that have signed up to voluntary programs for GHG emission reductions has increased from fewer than 50 at the start of the 1990s to several hundred by the early 2000s (Bulkeley and Betsill, 2003), and several thousand by 2012 (Kern and Bulkeley, 2009; Pitt, 2010; Krause, 2011a). For example, in 2012 the European Covenant of Mayors had over 3,800 members representing some 160 million Europeans; while in the U.S., over 1,000 municipalities, representing approximately 30% of the country's population, have formally committed to reduce local GHG emissions through their participation in one of several climate-protection networks (Krause, 2011a). While the development of local climate policy has historically been dominated by municipalities in the “North,” cities in the “Global South” are increasingly engaging with the mitigation agenda (Romero Lankao, 2007; Pitt, 2010). This reflects at least in part the expansion of transnational municipal networks in these regions and the changing international politics of climate change.

For example, in Japan, the Global Warming Law and the Kyoto Protocol Target Achievement Plan mandate that 1,800 municipal governments and 47 Prefectures prepare climate change mitigation action plans (Sugiyama and Takeuchi, 2008). In other countries, the lack of federal governmental leadership on climate change policy and local factors provide a political opportunity for city governments to take leadership and devise city climate action plans. Between 2004 and 2007, 684 cities signed the U.S. Mayors’ Climate Protection Agreement, representing 26% of the U.S. population and accounting for 23% of the country’s GHG emissions (Lutsey and Sperling, 2008). Similarly, there are climate change efforts in many European cities despite a lack of national legislation for emissions targets (Bulkeley and Kern, 2006). Cities in emerging economies are also showing a willingness to engage in and develop climate plans via non-obligatory commitments.

Beyond these regional patterns, there is limited evidence that explains why some municipalities rather than others have joined voluntary programs, often in the face of explicit national opposition to climate change action (e.g. in the US and Australia). The majority of evidence has been collected from “pioneer” municipalities, and concludes that the presence of policy entrepreneurs, windows of opportunity provided by urban initiatives, and a permissive political context at the local level have been critical to the development of local climate initiatives (Betsill and Bulkeley, 2007). Assessments of a range of contextual variables have been made in the U.S., where some researchers have found that a combination of vulnerability to climate change, low levels of contribution to the climate change problem, and “civic capacity” (indicated by socioeconomic factors such as income, levels of education, political support) can explain the likelihood of membership in the Cities for Climate Protection campaign (Brody et al., 2008; Zahran et al., 2008). In contrast, other U.S.-based studies

Table 12.12: Climate change actions for selected cities. Municipal climate action plans incorporate a various sectors, actors, and GHG reduction targets in developing a comprehensive climate change mitigation strategies.

City	Mitigation actions: Transport							Buildings					Energy				Waste							
	Public	Non-motorized	Hybrid / Electric / Efficient vehiles / Biofuels	Car pooling / car sharing / High Occupancy	Parking charges, road pricing, subsides & other economic measures	Vehicle verification / Limits of emissions / filter requirement	Others	Energy efficiency	Building codes / Buildings renovation	Retrofitting	Financial measures (subsides, incentives)	Others	Efficiency	Alternative Energies	Financial measures	Other	Integrated waste management (avoiding waste, separation, reuse, composting, recycling)	Plastic management /reduction	Energy production	Waste water	Water supply	Land planning / Mixed use land (explicitly indicated)	Green spaces	Education, Consumption awareness and others
NORTH AMERICA																								
Toronto (metro)	X	X			X	X		X	X	X														
Vancouver	X	X	X	X				X	X	X							X			X	X	X	X	X
Calgary	X	X	X	X	X			X	X	X		X	X	X			X		X	X	X			
Evanston	X	X	X	X				X	X	X				X			X				X	X	X	X
Denver	X	X	X	X				X	X	X			X	X			X					X		
Chicago	X	X	X	X				X	X	X			X	X			X					X	X	X
Los Angeles	X	X	X					X	X	X			X	X			X			X	X	X	X	
Miami	X	X	X	X	X			X	X	X			X	X								X	X	
New York City	X	X	X	X		X		X	X	X	X	X	X	X	X		X		X	X	X	X	X	X
Berkley	X	X	X	X				X	X				X	X			X	X			X		X	X
Belmont	X	X	X	X				X	X	X			X	X			X							
Boulder	X	X		X				X	X	X	X		X	X			X							X
Pittsbourgh	X	X	X		X		X	X	X	X			X	X			X			X	X	X	X	X
Piedmont	X	X						X	X	X			X	X			X				X	X		
Philadelphia	X	X	X		X			X	X	X		X	X	X			X			X		X	X	
Portland	X		X					X	X	X	X		X	X			X					X	X	X
San Francisco	X	X	X	X				X	X	X			X	X			X							
Seatle	X	X	X	X	X			X	X	X			X	X		X						X	X	
Mexico City	X	X				X	X	X	X	X			X	X			X		X	X	X			
SOUTH AMERICA																								
Buenos Aires	X	X	X				X	X	X	X			X	X			X			X				
Rio de Janeiro	X	X	X				X	X		X			X	X			X		X	X		X	X	
Sao Paolo	X	X	X					X	X	X			X	X			X		X	X		X	X	
La Paz	X	X				X		X	X				X	X			X			X	X			
Quito	X	X						X					X	X			X			X	X	X	X	X
Montevideo*	X	X											X	X			X			X	X		X	
Bogota	X	X	X						X	X							X					X	X	
EUROPE																								
Brussels	X	X		X			X	X	X		X		X				X	X						X
Helsinki	X	X			X	X		X	X	X	X	X	X	X			X					X		X
Paris (Île de	X	X	X		X		X	X	X	X	X		X	X		X	X	X				X	X	X
Hamburg	X	X	X					X	X			X	X	X										X
Stuttgart	X	X						X	X	X			X	X			X							X
Athens	X	X			X		X	X	X					X	X		X	X					X	X
Rome	X	X											X			X	X						X	X
Rotterdam	X	X						X					X	X								X	X	X
Amsterdam	X	X		X	X		X	X	X				X	X			X							X
Oslo	X	X	X					X		X	X		X		X		X		X	X				X
Madrid	X	X						X	X	X			X	X			X		X			X	X	X
Barcelona	X					X	X	X	X	X							X							X
Stockholm	X	X						X					X			X								X

Table 12.12: Continued

City	Mitigation actions																							
	Transport							Buildings					Energy				Waste							
	Public	Non-motorized	Hybrid / Electric / Efficient vehiles / Biofuels	Car pooling / car sharing / High Occupancy	Parking charges, road pricing, subsides & other economic measures	Vehicle verification / Limits of emissions / filter requirement	Others	Energy efficiency	Building codes / Buildings renovation	Retrofiting	Financial measures (subsides, incentives)	Others	Efficiency	Alternative Energies	Financial measures	Other	Integrated waste management (avoiding waste, separation, reuse, composting, recycling)	Plastic management /reduction	Energy production	Waste water	Water supply	Land planning / Mixed use land (explicitly indicated)	Green spaces	Education, Consumption awareness and others
AFRICA																								
Cape Town	X						X	X	X	X			X	X	X				X			X	X	X
Johannesburg	X	X	X				X	X		X	X		X	X			X		X			X	X	X
ASIA																								
Beijing	X	X	X		X			X	X				X	X		X								X
Hong Kong	X	X	X		X			x	X		X		X	X	X	X							X	X
Changwon	X	X						X	X		X		X	X	X		X	X	X				X	X
Delhi	X	X	X		x			X	X	X			X	X			X	X	X	X	X		X	X
Gorakhpur city*	X	X	X					X			X		X	X			X			X	X			X
Surat*	X	X		X	X			X	X				X	X		X			X	X	X	X		
Indore*	X	X						X	X				X	X			X			X	X			
Semarang*	X		X					X	X				X	X	X		X			X	X	x	X	X
Amman	X	X						X	X				X			X	X		X	X	X	X		
Sorgoson city	X					X		X	X	X			X	X	X	X	X			X	X		X	X
Changwon	X	X	X					X	X		X	X	X	X			X	X	X				X	X
Singapore city*	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Bangkok	X	X	X		X			X				X	X	X			X	X	X	X			X	
Tokyo	X	X	X	X	X		X	X	X		X		X	X	X	X								X
Nagoya																								
Kitakyushu	X	X	X		X			X	X		X		X	X	X		X	X			X		X	X
Yokohama	X	X	X	X				X	X	X		X	X	X			X					X		X
Da Nang*																					X	X	X	X
CanTho*								X					X	X			X			X	X	X	X	X
OCEANIA																								
Syndey	X	X				X		X					X	X			X					X	X	
Cairns	X	X		X				X	X	X			X	X			X			X	X		X	X
Melbourne	X	X						X	X	X			X	X			X				X			X
Brisbane	X	X	X		X		X	X	X	X			X	X			X			X	X	X	X	X
Wellington	X	X	X				X	X	X	X			X	X			X					X	X	X
Auckland	X	X			X			X	X	X			X	X			X				X	X	X	X

have corroborated earlier case-study research findings that the political/institutional support within municipalities most clearly explains the adoption of climate change policies (Pitt, 2010) and to some extent the level of action being undertaken (Krause, 2011a).

12.7.2 Cross-cutting goals

Municipalities have developed a range of climate change strategy and action plans which are often cross-cutting in nature, but may not be well coordinated with urban land use and transportation policy or take into account other pressures and drivers in these policy domains. Where climate policy goals are more integrated with other policy sectors, there is some evidence that more ambitious goals have been set and specific sectoral policies have been changed. For example, in London the integration of climate change policy with the Greater London Plan led to changes in the planning requirements for the integration of renewable energy generation within developments over a certain size.

12.7.3 Targets and timetables

Across the different contexts within which climate change policy has been adopted at the municipal level, studies have identified similar policy approaches based on an ideal-model of developing GHG emissions inventories, setting targets and timetables for GHG emissions reductions, producing an action plan, implementation, and progress monitoring (Lutsey and Sperling, 2008; Alber and Kristine, 2011). This model has been advanced particularly by the ICLEI Cities for Climate Protection (CCP) programme, with variations developed by Climate Alliance and C40, and in practice has often been initially applied to the GHG emissions for which municipalities are directly responsible before being extended to urban jurisdictions.

A central feature of municipal climate change responses is that targets and timetables have frequently exceeded the ambition displayed at the international and national level. In the U.S., signatories to the Mayors Climate Protection Agreement have pledged to reduce GHG emissions by 7% below 1990 levels by 2012, in line with the target agreed upon in the Kyoto Protocol for the U.S. (Krause, 2011b). In Europe and Australia, several municipalities have adopted targets of reducing GHG emissions by 20% by 2020 and long-term targets for radically reducing GHG emissions, including "zero-carbon" targets in the City of Melbourne and Moreland (Victoria), and a target of 80% reduction over 1990 levels by 2050 in London (Bulkeley, H, 2009). This is not an approach that has been confined to cities in more developed economies. For example, in Cape Town a target of increasing energy efficiency within the municipality by 12% by 2010 has been set (Holgate, 2007), and Mexico City has implemented a target of reducing GHG by 12% below 1990 levels by 2012 (Romero Lankao, 2007).

Tokyo's climate action plan presents clear targets supplemented by mandatory local law, scientific accounting of GHG, actions and institutional capacity. In contrast, Delhi's climate agenda is largely a preliminary attempt to develop climate actions as the city confronts the need to deal with other basic priorities. For example, the Delhi Climate Change Agenda only reports Delhi's CO_2 emissions from power, transport and domestic sectors as 22.49 $MtCO_2$ for 2007-8 (SOE Delhi, 2010) while the contribution of the commercial sectors and industries comprise a larger share of the city's total emissions. Furthermore, Delhi's climate action plan lacks clear GHG reduction targets, analysis of the total carbon reductions projected under the plan, and a strategy for how to achieve their emissions goals. Similar limitations are apparent in climate mitigation plans for other global cities such as Bangkok and Jakarta (Dhakal and Poruschi, 2010). For many cities in developing countries a reliable city GHG inventory may not exist, making the climate change actions largely symbolic. However, these city action plans provide a foundation for municipal engagement in mitigation initiatives while building momentum for collective action on a global scale.

12.7.4 Climate action plan implementation

There is considerable variation in the nature and quality of climate change plans that have been developed in order to address local policy goals, particularly when it comes to specifying the detail of actions and approaches to implementation (Wheeler, 2008; Tang et al., 2011; Bulkeley and Schroeder, 2012). Urban climate action plans focus on a large range of potential initiatives across sectors as varied as land use planning, transportation, energy, waste, built environment (Schreurs, 2008; Wheeler, 2008). Despite this variation, attention has tended to focus on issues of energy efficiency, particularly in the built environment (Bulkeley and Kern, 2006). Energy efficiency is a particularly potent issue, as it can "advance diverse (and often divergent) goals in tandem" (Rutland and Aylett, 2008), serving to translate various interests into those concerning climate change and effectively forging new partnerships. In contrast, there has been less engagement by municipalities with sectors such as energy and water supply that often lie outside their jurisdiction (Bulkeley and Kern, 2006; Arup, 2011) or with the GHG emissions embodied in present patterns of urban resource use and consumption (Figure 12.20) (Rutland and Aylett, 2008; Dodman, 2009).

Despite the implementation of comprehensive climate action plans and policies, progress for cities in developed countries is slow and the achievability of emissions targets remains uncertain. Although municipalities often highlight progress on climate mitigation projects, the impacts of these initiatives may not be evaluated. In Germany, nearly 75% of cities with a GHG target established their emissions goals based on national or international metrics rather than local analysis of mitigation options (Sippel, 2011). There, cities' mitigation reduction performance is largely correlated to the national performance.

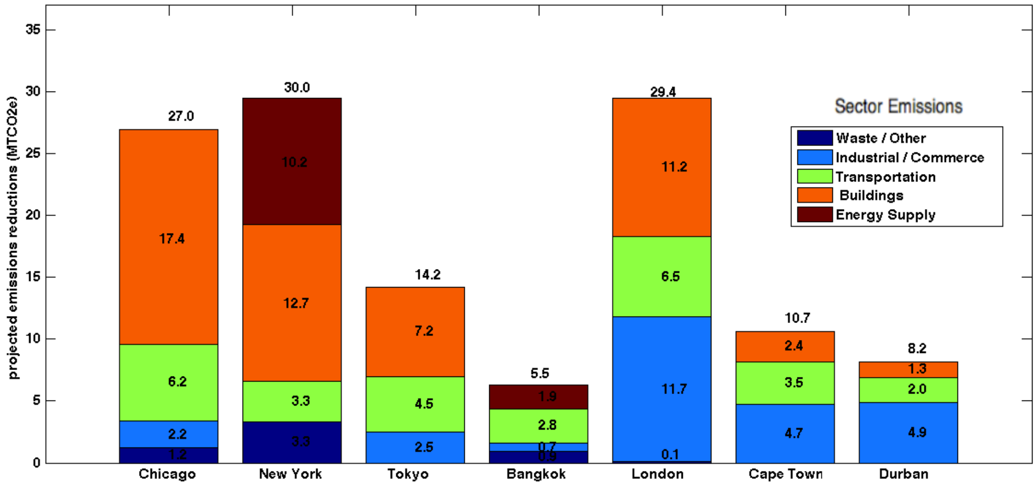


Figure 12.20. Sector-based GHG emission reductions targets for select global cities.Source: (GLA, 2007; Chicago Metropolitan Agency for Planning, 2010; *Bangkok Metropolitan Administration Action Plan on Global Warming Mitigation 2007-2012*, 2007, *Cape Town Energy and Climate Change Strategy*, *PlaNYC 2030: A Greener, Greater New York*, 2011; TMG, 2008; ASSAF, 2011)

12.7.5 Citizen participation and grass-root initiatives

Household responses to mitigation programs such as car-pooling or use of solar power influences the likelihood of their success. In particular, public awareness of climate change impacts the extent to which households and civic groups invest time, energy and money in mitigation activities (Kates and Wilbanks, 2003). This can be encouraged through education, awareness building, persuasion and promotion by civil society groups and governments, targeted at locations such as local schools (Alber and Kristine, 2011). Peer pressure through community monitoring can also help build social capital of local urban communities to follow mutually agreed upon policies for climate change mitigation (Ostrom, 2010).

The degree of citizen participation in piloting urban mitigation initiatives can influence their long term impact. In many cities such as Cape Town, South Africa, local organizations have been influential in enabling city planners and parastatal organizations to provide people-centered programs for urban mitigation through ecosystem restoration (Ernstson et al., 2010). Similar urban conservation and mitigation programs are found in many parts of the world, yet often dominated by middle class residents, sometimes excluding vulnerable and poor sections of society from decision making and benefit-sharing (D'Souza and Nagendra, 2011).

Civil society organizations include workers' associations. In many developing country cities, waste pickers indirectly assist in mitigation by recycling materials that would otherwise be disposed of in landfills and incinerators. In Delhi, informal waste pickers contribute an estimated net GHG reduction of 962,133 tons of carbon dioxide equivalent (TCO e) each year (Chintan, 2009). Organized into cooperatives and associations, waste pickers in Brazil have developed partnerships with city governments to improve access to waste, better prices and better facilities that improve working conditions while increasing their contribution to mitigation (Fergutz, Dias and Mitlin 2011).

12.8 Sustainable development, co-benefits, tradeoffs, and spillovers

Efforts to address GHG emissions from human settlements interact both positively and negatively with many aspects of sustainable development. Key urban mitigation strategies related to land use, urban design, buildings, infrastructure, and in particular, transport are often key elements of urban sustainability agendas, but some strategies may involve trade-offs with other climate adaptation or sustainability goals, or may have adverse spillover effects. The potential trade-offs and spillover effects of urban mitigation strategies require special attention when they affect vulnerable populations, such as the urban poor. The sections on the urban heat island effect and green urban sinks illustrate the interaction of mitigation strategies with adaptation and sustainable development strategies.

12.8.1 Co-benefits and adaptation synergies of mitigating the Urban Heat Island

The urban heat island effect illustrates the co-benefits and trade-offs among sustainable development, climate change mitigation and adaptation strategies in settlements. The urban heat island (UHI) effect, in which urban areas are warmer than surrounding areas has been observed since at least 1833 (Myrup, 1969). The UHI occurs in part due to absorption of solar radiation by dark surfaces such as roofs and pavement and re-radiation from urban structures (RIZWAN et al., 2008). In dense cities such as Tokyo, the density of heat discharge within the city by buildings due to air conditioners is high and energy can contribute to increases of 3-4 ^{o}C in temperature (Dhakal and Hanaki, 2002).

The UHI presents a major challenge to urban sustainability. Not only does UHI increase the use of energy for cooling buildings and thermal discomfort in urban areas, but UHI also increases smoggy days in urban areas, with smog health effects present above 32 degrees C (Akbari et al., 2001). Proven methods for cooling the urban environment include urban greening, increasing openness to allow cooling winds (Smith and Levermore, 2008), and using more “cool” or reflective materials that absorb less solar radiation, i.e., increasing the albedo of the surfaces (Akbari et al., 2008; Akbari, 2010). Reducing UHI is most effective when considered in conjunction with other environmental aspects of urban design, including solar/daylight control, ventilation and indoor environment, and streetscape (Yang et al., 2010). Calculations based upon physical principles indicate that the effect of substituting cool materials is significant, resulting in cooler temperatures. In addition to white roofs or pavements, a range of cool materials in a variety of colors have been developed which reduce absorption of solar radiation. On a global scale, increasing albedos of urban roofs and paved surfaces is estimated to induce a negative radiative forcing equivalent to offsetting about 44 Gt of CO2 emissions (Akbari et al., 2008).

Reducing summer heat in urban areas has several co-benefits. Electricity use in cities increases 2-4% for each 1 degree C increase in temperature, due to air conditioning use (Akbari et al., 2001). Lower temperatures reduce energy requirements for air conditioning (which may result in decreasing greenhouse gas emissions from electricity generation, depending upon the sources of electricity), reduce smog levels (Rosenfeld et al., 1998), and reduce the risk of morbidity and mortality due to heat and poor air quality (Harlan and Ruddell, 2011). Cool materials decrease the temperature of surfaces and increase the lifespan of building materials and pavements (Santero and Horvath, 2009; Synnefa et al., 2011).

The projected temperature increases under climate change will disproportionally impact cities already affected by UHI, thereby increasing the energy requirements for cooling buildings and increasing urban carbon emissions, as well as air pollution. In addition, there is likely to be an increase in cities experiencing UHI as a result of projected increases in temperature under climate change, which will result in additional global urban energy use, GHG emissions, and local air pollution. As reviewed here, studies indicate that several strategies are effective in decreasing the UHI. An effective strategy to mitigate UHI through increasing green spaces, however, can potentially conflict with a major urban climate change mitigation strategy, increasing densities to create more compact cities. This illustrates the complexity of developing integrated and effective climate change policies for urban areas.

12.8.2 Urban carbon sinks

Urban carbon sinks include a variety of vegetation types including urban forests, wetlands, parks, grasslands and green roofs. In addition to carbon sequestration, they can provide co-benefits for adaptation, by offering ecosystem services that include the provision of shade and cooling, rainwater interception and infiltration, reduction in pollution, biodiversity support, and enhancement of wellbeing (Heynen et al., 2006; Gill et al., 2007; McDonald, 2008). They have a high capacity to reduce urban carbon footprints. Estimates in Hangzhou, China, indicate that urban forests can annually offset 18.6% of industrial C emissions (Zhao et al., 2010), although other studies in Leipzig, Germany indicate that the mitigation provided by urban green spaces is limited in comparison to the extent of urban emissions (Strohbach, Arnold and Haase 2012).

Most studies that assess the extent of carbon sequestration in cities have been conducted in western countries, and limited information is available for cities outside Europe and the US. In the US, urban forests are estimated to sequester an average of 25.1 t C ha^{-1} above ground, less than half of that for forest stands (Nowak, D.J. et al., 2002).The total organic carbon sequestered in urban vegetation and soils can be as high as 115.6 t ha^{-1} in the US, much greater than those of rural forest soils. In European cities, above ground C sequestration is estimated to be an average of 31.6 t ha^{-1} in Leicester, UK (Davies et al., 2011), 11.8 t ha^{-1} in Leipzig, Germany (Strohbach and Haase 2012), and 11.2 t ha^{-1} in Barcelona, Spain (Chaparro and Tarradas 2009). In the South Korean cities of Chuncheon, Kangleung and Seoul, mean above and belowground carbon storage is estimated to be much lower, ranging from 4.7 to 7.2 t ha^{-1} (Hyun-kil, 2002), while in Hangzhou, China, above ground carbon sequestration is estimated to be much higher, 30.3 t ha^{-1} (Zhao et al., 2010). Thus there are considerable differences between reported values from different cities. It is difficult to establish comparisons, in part due to the differences in methodologies of estimation, but mainly due to critical differences in the definition of urban areas, with some city studies including natural forests, parks and built areas within urban boundaries, while others focus mainly on urban forests.

Most studies conclude that areas dominated by tree cover (mainly urban forests) offer the greatest potential for mitigation. Here, differences in the vegetation type seem to impact the degree of carbon sequestration possible, with above ground carbon sequestration in urban forests and wooded areas ranging from 30.25 t ha^{-1} in Hangzhou and 33.3 t ha^{-1} in Barcelona (Chaparro and Tarradas 2009) to 98.26 t ha^{-1} in Leipzig (Strohbach and Haase 2012) and 288.6 t ha^{-1} in Leicester, UK (Davies et al., 2011) - although some of these differences could also be attributed to variations in methodologies for assessment. Yet, the long term impacts of such mitigation will be impacted if trees are pruned or cut, and wood is disposed of through burning or other means. Assumptions of tree growth and mortality rates can thus add significant uncertainty to estimates of long term carbon sequestration. In Leipzig, for instance, studies have shown that an increase in tree mortality rates from 0.5% to 4% annually can decrease carbon sequestration by as much as 70% (Strohbach et al. 2012).

In addition to carbon sequestration, urban vegetation can contribute to indirect mitigation by reducing airborne pollution (Brack, 2002) - although plants can also rarely become a source of pollution through pollen and the emission of volatile organic compounds (Yang et al., 2008). Tree planting also provides significant overall mitigation benefits by reducing overall energy consumption (Akbari and Konopacki, 2005; Pataki et al., 2006), resulting in as much as 6-7 °C reductions in midday temperatures (Pauleit and Duhme, Friedrich, 2000; Whitford et al., 2001). The indirect mitigation benefits provided by urban forests depend on the species, size, and location. Large trees provide increased shade and capacity to reduce air pollution. Evergreen species provide year round cooling in the tropics, but can be less useful in temperate climates where they may shade out the winter sun (Brack, 2002).

Lawns and turfgrass constitute common urban features, and provide some, albeit limited opportunities for C sequestration. Golf courses in the US have average annual rates of sequestration of 0.9-1 t C ha^{-1} during the first 25-30 years after establishment (Qian, Yaling and Follet, Ronald F., 2002). Carbon sequestration in urban lawns and turfgrass soils can substantially surpass initial levels in less than two decades and exceed those of production agriculture and tallgrass prairie, due to intensive management, irrigation and fertilization (Qian, Yaling and Follet, Ronald F., 2002). Green roofs and green walls provide another, currently limited but fast growing category of urban green space with potential for large scale modification through planting (Yang et al., 2008; Getter et al., 2009).

However, in practice the net positive or negative contributions to global warming of these different types of urban green spaces will depend on the carbon "cost" of establishment in terms of the embodied energy of the installed components, the energy costs of maintenance and management practices, the degree of application of inorganic fertilizers, and possible emissions of greenhouse gases due to fertilizer application (Nowak, D.J. et al., 2002; Kaye et al., 2004; Bijoor et al., 2008; Townsend-Small and Czimczik, 2010). Intensively managed urban green spaces often require the frequent use of fuel-operated machinery, and regular visits for watering and maintenance, leading to increased fuel combustion. The application of fertilizers, pruning and removal of dead and dangerous branches and trees can also lead to increased emissions, although the manner in which removed wood is used impacts the net carbon accounting. Leaf fall from trees reduces above ground carbon sequestration, but can contribute to an increase in soil organic carbon. Green roofs and urban forests therefore may only be able to compensate for the C expenditure incurred during planting, installation and establishment a few years after establishment (Sailor,D.J., 2008; Stoffberg et al., 2010).

There is significant potential for increasing the carbon storage in cities. In Leicester, for instance, a 10% increase in planting in areas with herbaceous cover could increase above ground C storage by 12% (Davies et al., 2011). In Tshwane, South Africa, a large scale plantation of over 115,000 street trees between 2002-2008 has had the potential to sequester 54,630 tonnes C by the year 2032 (Stoffberg et al., 2010). Since exurban areas have a greater proportion of green cover compared to urban areas, low density urbanization may also lead to an enhancement in regional CO2 uptake (Zhao, Tingting et al., 2007; Churkina et al., 2010). Land use, spatial planning and zoning issues will have significant influence on the extent and spatial distribution of urban carbon sinks, impacting mitigation. Yet urban planners rarely pay sufficient attention to the importance of urban green spaces. Thus, the area and capacity of urban carbon sinks have grown or shrunk in different ways in different parts of the world, based on the nature of urban growth and attitudes towards urbanization (Escobedo et al., 2006; Pincetl, 2009; Nagendra and Gopal, 2010; Davies et al., 2011). Currently, there is a significant gap in knowledge about cities outside the US and Europe.

12.9 Gaps in knowledge

There are five significant gaps in knowledge. First, there is a lack of available, consistent, and comparable emissions data at local scales. Although some emissions data collection efforts are underway, they have been undertaken primarily in large cities in developed countries. The lack of baseline data makes it particularly challenging to assess the efficacy of individual climate action plans.

Second, there is little consistency and no consensus on local emissions accounting methods. Different accounting protocols yield significantly different results, making cross-city comparisons of emissions or climate action plans difficult. There is a need for standardized methodologies for local- or urban-level carbon accounting.

Third, local and urban governments and civil society are taking leadership to reduce carbon emissions, but there are few evaluations of these urban climate action plans and their effectiveness. There is no systematic accounting to evaluate the efficacy of city climate action plans (Zimmerman and Faris, 2011). Studies that have examined city climate action plans conclude that they are unlikely to have significant impact on reducing overall emissions (Millard-Ball, 2012; Stone et al., 2012). Another major limitation to local or city climate action plans is their limited coordination across city sectors and administrative/hierarchical levels of governance and lack of explicitly incorporating land-based mitigation strategies. Successful local climate action plans will require coordination, integration, and partnerships among community organizations, local government, state and federal agencies, and international organizations (Yalçın and Lefèvre, 2012; Zeemering, 2012).

Fourth, there is also a lack of scientific understanding on how cities can prioritize climate change mitigation strategies, local actions, investments, and policy responses that are locally relevant. Some cities will be facing critical vulnerability challenges, others will be in the “red zone” for their high levels of emissions. Local decision-makers need clarity on where to focus their actions, and avoid dispersing efforts in policies and investments which are not essential. There is little scientific basis for identifying the right mix of policy responses to address local and urban level mitigation and adaptation. Such policy packages will be based on the characteristics of cities and urbanization and development pathways, but also on the forecasting of future climate and urbanization. They will be aimed at flexing the urban- and settlement-related “drivers” of emissions and vulnerability in order to ensure a less carbon-intensive and more resilient future for cities.

Fifth, there are large uncertainties as to how future human settlements and cities will develop in the future. By the end of the 21st century, the global population is expected to increase by 3 billion, with a majority of the growth in urban areas. There is strong scientific evidence that emissions vary across human settlements, and that urban form, metabolism, and governance play large roles in determining these relationships. How the human settlements of tomorrow are developed, built, and managed will have significant impacts on local, and ultimately global emissions.

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