INTERGOVERNMENTAL PANEL ON climate change
Working Group III – Mitigation of Climate Change

Chapter 12

Human Settlements, Infrastructure and Spatial Planning

A report accepted by Working Group III of the IPCC but not approved in detail.

Note:

This document is the copy-edited version of the final draft Report, dated 17 December 2013, of the **Working Group III contribution to the IPCC 5th Assessment Report "Climate Change 2014: Mitigation of Climate Change" that was accepted but not approved in detail by the 12th Session of Working Group III and the 39th Session of the IPCC on 12 April 2014 in Berlin, Germany**. It consists of the full scientific, technical and socio-economic assessment undertaken by Working Group III.

The Report should be read in conjunction with the document entitled "Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the IPCC 5th Assessment Report - Changes to the underlying Scientific/Technical Assessment" to ensure consistency with the approved Summary for Policymakers (WGIII: 12th/Doc. 2a, Rev.2) and presented to the Panel at its 39th Session. This document lists the changes necessary to ensure consistency between the full Report and the Summary for Policymakers, which was approved line-by-line by Working Group III and accepted by the Panel at the aforementioned Sessions.

Before publication, the Report (including text, figures and tables) will undergo final quality check as well as any error correction as necessary, consistent with the IPCC Protocol for Addressing Possible Errors. Publication of the Report is foreseen in September/October 2014.

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Chapter 12: Human Settlements, Infrastructure, and Spatial Planning

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Executive Summary

The shift from rural to more urban societies is a global megatrend with significant consequences for greenhouse gas (GHG) emissions and climate change mitigation. Across multiple dimensions, the scale and speed of urbanization is unprecedented: more than half of the world population live in urban areas and each week the global urban population increases by 1.3 million. Today there are nearly 1000 urban agglomerations with populations of 500,000 or greater; by 2050, the global urban population is expected to increase by between 2.5 to 3 billion, corresponding to 64% to 69% of the world population [*robust evidence, high agreement]*. Expansion of urban areas is on average twice as fast as urban population growth, and the expected increase in urban land cover during in the first three decades of the 21st century will be greater than the cumulative urban expansion in all of human history [*medium evidence, high agreement].* Urban areas generate around 80% of global Gross Domestic Product (GDP) [*medium evidence, medium agreement*]. [Sections 12.1, 12.2].

Current and future urbanization trends are significantly different from the past *[robust evidence, high agreement]*. Urbanization is taking place at lower levels of economic development and the majority of future urban population growth will take place in small- to medium-sized urban areas in developing countries. Expansion of urban areas is on average twice as fast as urban population growth, and the expected increase in urban land cover during the first three decades of the 21st century will be greater than the cumulative urban expansion in all of human history (*robust evidence, high agreement*). [12.1, 12.2]

Urban areas account for between 71% and 76% of CO_2 emissions from global final energy use and between 67–76% of global energy use *[medium evidence, medium agreement]*. There are very few studies that have examined the contribution of all urban areas to global GHG emissions. The fraction of global CO_2 emissions from urban areas depends on the spatial and functional boundary definitions of urban and the choice of emissions accounting method. Estimates for urban energy related CO_2 emissions range from 71% for 2006 to between 53% and 87% (central estimate, 76%) of CO_2 emissions from global final energy use *[medium evidence, medium agreement]*. There is only one attempt in the literature that examines the total GHG (CO_2, CH_4, N_2O and SF_6) contribution of urban areas globally, estimated at between 37% and 49% of global GHG emissions for the year 2000. Using Scope1 accounting, urban share of global CO_2 emissions is about 44% (*limited evidence, medium agreement*). [12.2]

No single factor explains variations in per-capita emissions across cities, and there are significant differences in per capita GHG emissions between cities within a single country *[robust evidence, high agreement]*. Urban GHG emissions are influenced by a variety of physical, economic and social factors, development levels, and urbanization histories specific to each city. Key influences on urban GHG emissions include income, population dynamics, urban form, locational factors, economic structure, and market failures *[robust evidence, high agreement]*. There is a prevalence for cities in Annex I countries to have lower per capita final energy use and GHG emissions than national averages, and for per capita final energy use and GHG emissions of cities in non-Annex I countries tend to be higher than national averages *(high agreement, robust evidence)* [12.3].

The anticipated growth in urban population will require a massive build-up of urban infrastructure, which is a key driver of emissions across multiple sectors *[limited evidence, high agreement]*. If the global population increases to 9.3 billion by 2050 and developing countries expand their built environment and infrastructure to current global average levels using available technology of today, the production of infrastructure materials alone would generate approximately 470 Gt of CO_2 emissions. Currently, average per capita CO_2 emissions embodied in the infrastructure of industrialized countries is five times larger than those in developing countries. The continued expansion of fossil fuel-based infrastructure would produce cumulative emissions of 2986–7402 $GtCO_2$ during the remainder of the 21st century (*high agreement, limited evidence).*[12.2, 12.3]

The existing infrastructure stock 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 *[medium evidence, medium agreement]*. The long life of infrastructure and the built environment, make them particularly prone to lock-in of energy and emissions pathways, lifestyles and consumption patterns that are difficult to change. The committed emissions from energy and transportation infrastructures are especially high, with respective ranges of 127–336 and 63–132 Gt, respectively (*medium evidence, medium agreement).* [12.3, 12.4]

Infrastructure and urban form are strongly linked, especially among transportation infrastructure provision, travel demand and vehicle kilometres travelled *[robust evidence, high agreement]*. In developing countries in particular, the growth of transport infrastructure and ensuing urban forms will play important roles in affecting long-run emissions trajectories *[robust evidence, high agreement]*. Urban form and structure significantly affect direct (operational) and indirect (embodied) GHG emissions, and are strongly linked to the throughput of materials and energy in a city, the wastes that it generates, and system efficiencies of a city *(robust evidence, high agreement).* [12.4, 12.5]

Key urban form drivers of energy and GHG emissions are density, land use mix, connectivity, and accessibility *[medium evidence, high agreement]*. These factors are interrelated and interdependent. Pursuing one of them in isolation is insufficient for lower emissions. Connectivity and accessibility are tightly related: highly connected places are accessible. While individual measures of urban form have relatively small effects on vehicle miles travelled, they become more effective when combined. There is consistent evidence that co-locating higher residential densities with higher employment densities, coupled with significant public transit improvements, higher land use mixes, and other supportive demand management measures can lead to greater emissions savings in the long run. Highly accessible communities are typically characterized by low daily commuting distances and travel times, enabled by multiple modes of transportation *(robust evidence, high agreement).* [12.5]

Urban mitigation options vary across urbanization trajectories and are expected to be most effective when policy instruments are bundled *[high evidence, high agreement]*. For rapidly developing cities, options include shaping their urbanization and infrastructure development towards more sustainable and low carbon pathways. In mature or established cities, options are constrained by existing urban forms and infrastructure and the potential for refurbishing existing systems and infrastructures. Key mitigation strategies include co-locating high residential with high employment densities, achieving high land use mixes, increasing accessibility and investing in public transit and other supportive demand management measures. Bundling these strategies can reduce emissions in the short term and generate even higher emissions savings in the long term (*high agreement, high evidence)*. [12.5]

Successful implementation of mitigation strategies at local scales requires that there be in place the institutional capacity and political will to align the right policy instruments to specific spatial planning strategies *[robust evidence, high agreement]*. Integrated land-use and transportation planning provides the opportunity to envision and articulate future settlement patterns, backed by zoning ordinances, subdivision regulations, and capital improvements programmes to implement the vision. While smaller scale spatial planning may not have the energy conservation or emissions reduction benefits of larger scale ones, development tends to occur parcel by parcel and urbanized areas are ultimately the products of thousands of individual site-level development and design decisions *(robust evidence, high agreement).* [12.5, 12.6]

The largest opportunities for future urban GHG emissions reduction might be in rapidly urbanizing countries where infrastructure inertia has not set in; however, the required governance, technical, financial, and institutional capacities can be limited *[high evidence, high agreement]*. The bulk of future infrastructure and urban growth is expected in small- to medium-size cities in developing countries, where these capacities can be limited or weak *[high agreement, high evidence].* [12.4, 12.5, 12.6, 12.7]

Thousands of cities are undertaking climate action plans, but the extent of urban mitigation is highly uncertain *[robust evidence, high agreement]*. Local governments and institutions possess unique opportunities to engage in urban mitigation activities and local mitigation efforts have expanded rapidly. However, little systematic reporting or evidence exists regarding the overall extent to which cities are implementing mitigation policies, and even less regarding their GHG impacts. Climate action plans include a range of measures across sectors, largely focused on energy efficiency rather than broader land-use planning strategies and cross-sectoral measures to reduce sprawl and promote transit-oriented development *[high evidence, high agreement]*. The majority of these targets have been developed for Annex I countries and reflect neither their mitigation potential nor implementation. Few targets have been established for non-Annex I country cities, and it is in these places where reliable city-level GHG emissions inventory may not exist *[high agreement, robust evidence].* [12.6, 12.7]

The feasibility of spatial planning instruments for climate change mitigation is highly dependent on a city's financial and governance capability *[robust evidence, high agreement]*. Drivers of urban GHG emissions are interrelated and can be addressed by a number of regulatory, management, and market-based instruments. Many of these instruments are applicable to cities in both developed and developing countries, but the degree to which they can be implemented varies. In addition, each instrument varies in its potential to generate public revenues or require government expenditures, and the administrative scale at which it can be applied. A bundling of instruments and a high level of coordination across institutions can increase the likelihood of achieving emissions reductions and avoiding unintended outcomes *[high agreement, robust evidence].* [12.6, 12.7]

For designing and implementing climate policies effectively, institutional arrangements, governance mechanisms, and financial resources should be aligned with the goals of reducing urban GHG emissions *[robust evidence, high agreement]*. These goals will reflect the specific challenges facing individual cities and local governments. The following have been identified as key factors: (1) institutional arrangements that facilitate the integration of mitigation with other high-priority urban agendas; (2) a multilevel governance context that empowers cities to promote urban transformations; (3) spatial planning competencies and political will to support integrated land-use and transportation planning; and (4) sufficient financial flows and incentives to adequately support mitigation strategies *[high agreement, robust evidence].* [12.6, 12.7]

Successful implementation of urban climate change mitigation strategies can provide co-benefits *[high evidence, high agreement]*. Co-benefits of local climate change mitigation can include public savings, air quality and associated health benefits, and productivity increases in urban centres, providing additional motivation for undertaking mitigation activities *[high agreement, high evidence].* [12.5, 12.6, 12.7, 12.8]

This assessment highlights a number of key knowledge gaps. First, there is lack of consistent and comparable emissions data at local scales, making it particularly challenging to assess the urban share of global GHG emissions as well as develop urbanization typologies and their emissions pathways. Second, there is little scientific understanding of the magnitude of the emissions reduction from altering urban form, and the emissions savings from integrated infrastructure and land use planning. Third, there is a lack of consistency and thus comparability on local emissions accounting methods, making cross-city comparisons of emissions or climate action plans difficult. Fourth, there are few evaluations of urban climate action plans and their effectiveness. Fifth, there is lack of scientific understanding of how cities can prioritize mitigation strategies, local actions, investments, and policy responses that are locally relevant. Sixth, there are large uncertainties about future urbanization trajectories, although urban form and infrastructure will play large roles in determining emissions pathways. [12.9]

12.1 Introduction

Urbanization is a global phenomenon that is transforming human settlements. The shift from primarily rural to more urban societies is evident through the transformation of places, populations, economies, and the built environment. In each of these dimensions, urbanization is unprecedented for its speed and scale: massive urbanization is a megatrend of the 21st century. With disorienting speed, villages and towns are being absorbed by, or coalescing into, larger urban conurbations and agglomerations. This rapid transformation is occurring throughout the world, and in many places it is accelerating.

Today, more than half of the global population is urban, compared to only 13% in 1900 (UN DESA, 2012). There are nearly 1,000 urban agglomerations with populations of 500,000 or more, three-quarters of which are in developing countries (UN DESA, 2012). By 2050, the global urban population is expected to increase by between 2.5 to 3 billion, corresponding to 64% to 69% of the world population (Grubler et al., 2007; IIASA, 2009; UN DESA, 2012). Put differently, each week the urban population is increasing by approximately 1.3 million.

Future trends in the levels, patterns, and regional variation of urbanization will be significantly different from those of the past. Most of the urban population growth will take place in small- to medium-sized urban areas. Nearly all of the future population growth will be absorbed by urban areas in developing countries (IIASA, 2009; UN DESA, 2012). In many developing countries, infrastructure and urban growth will be greatest, but technical capacities are limited, and governance, financial, and economic institutional capacities are weak (Bräutigam and Knack, 2004; Rodrik et al., 2004). The kinds of towns, cities, and urban agglomerations that ultimately emerge over the coming decades will have a critical impact on energy use and carbon emissions.

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) did not have a chapter on human settlements or urban areas. Urban areas were addressed through the lens of individual sector chapters. Since the publication of AR4, there has been a growing recognition of the significant contribution of urban areas to GHG emissions, their potential role in mitigating them, and a multi-fold increase in the corresponding scientific literature. This chapter provides an assessment of this literature and the key mitigation options that are available at the local level. The majority of this literature has focused on urban areas and cities in developed countries. With the exception of China, there are few studies on the mitigation potential or GHG emissions of urban areas in developing countries. This assessment reflects these geographic limitations in the published literature.

Urbanization is a process that involves simultaneous transitions and transformations across multiple dimensions, including demographic, economic, and physical changes in the landscape. Each of these dimensions presents different indicators and definitions of urbanization. The chapter begins with a brief discussion of the multiple dimensions and definitions of urbanization, including implications for GHG emissions accounting, and then continues with an assessment of historical, current, and future trends across different dimensions of urbanization in the context of GHG emissions (12.2). It then discusses GHG accounting approaches and challenges specific to urban areas and human settlements.

In Section 12.3, the chapter assesses the drivers of urban GHG emissions in a systemic fashion, and examines the impacts of drivers on individuals sectors as well as the interaction and interdependence of drivers. In this section, the relative magnitude of each driver's impact on urban GHG emissions is discussed both qualitatively and quantitatively, and provides the context for a more detailed assessment of how urban form and infrastructure affect urban GHG emissions (12.4). Here, the section discusses the individual urban form drivers such as density, connectivity, and land use mix, as well as their interactions with each other. Section 12.4 also examines the links between infrastructure and urban form, as well as their combined and interacting effects on GHG emissions.

Section 12.5 identifies spatial planning strategies and policy instruments that can affect multiple drivers, and Section 12.6 examines the institutional, governance, and financial requirements to implement such policies. Of particular importance with regard to mitigation potential at the urban or local scale is a discussion of the geographic and administrative scales for which policies are implemented, overlapping, and/or in conflict. The chapter then identifies the scale and range of mitigation actions currently planned and/or implemented by local governments, and assesses the evidence of successful implementation of the plans, as well as barriers to further implementation (12.7). Next, the chapter discusses major co-benefits and adverse side-effects of mitigation at the local scale, including opportunities for sustainable development (12.8). The chapter concludes with a discussion of the major gaps in knowledge with respect to mitigation of climate change in urban areas (12.9).

12.2 Human Settlements and GHG Emissions

This section assesses past, current, and future trends in human settlements in the context of GHG emissions. It aims to provide a multi-dimensional perspective on the scale of the urbanization process. This section includes a discussion of the development trends of urban areas, including population size, land use, and density. Section 12.2.1 outlines historic urbanization dynamics in multiple dimensions as drivers of GHG emissions. Section 12.2.2 focuses on current GHG emissions. Finally, Section 12.2.3 assesses future scenarios of urbanization in order to frame the GHG emissions challenges to come.

Box 12.1. What is urban? The system boundary problem

Any empirical analysis of urban and rural areas, as well as human settlements, requires clear delineation of physical boundaries. However, it is not a trivial or unambiguous task to determine where a city, an urban area, or human settlement physically begins and ends. In the literature, there are a number of methods to establish the boundaries of a city or urban area (Elliot, 1987; Buisseret, 1998; Churchill, 2004). Three common types of boundaries include:

1. **Administrative boundaries**, which refer to the territorial or political boundaries of a city (Hartshorne, 1933; Aguilar and Ward, 2003).
2. **Functional boundaries**, which are delineated according to connections or interactions between areas, such as economic activity, per capita income, or commuting zone (Brown and Holmes, 1971; Douglass, 2000; Hidle et al., 2009).
3. **Morphological boundaries**, which are based on the form or structure of land use, land cover, or the built environment. This is the dominant approach when satellite images are used to delineate urban areas (Benediktsson et al., 2003; Rashed et al., 2003).

What approach is chosen will often depend on the particular research question under consideration. The choice of the physical boundaries can have a substantial influence on the results of the analysis. For example, the Global Energy Assessment (GEA) (GEA, 2012) estimates global urban energy consumption between 180–250 EJ/yr depending on the particular choice of the physical delineation between rural and urban areas. Similarly, depending on the choice of different administrative, morphological, and functional boundaries, between 37% and 86% in buildings and industry, and 37% to 77% of mobile diesel and gasoline consumption can be attributed in urban areas (Parshall et al., 2010). Thus any empirical evidence presented in this chapter is dependent on the particular boundary choice made in the respective analysis.

12.2.1 The role of cities and urban areas in energy use and GHG emissions

Worldwide, 3.3 billion people live in rural areas, the majority of whom, about 92%, live in rural areas in developing countries (UN DESA, 2012). In general, rural populations have lower per capita energy consumption compared with urban populations in developing countries (International Energy Agency, 2008). Globally, 32% of the global rural population lack access to electricity and other modern energy sources, compared to only 5.3% of the urban population (International Energy Agency, 2010). Hence, energy use and GHG emissions from human settlements is mainly from urban areas rather than rural areas, and the role of cities and urban areas in global climate change has become increasingly important over time.

Urbanization involves change across multiple dimensions and accordingly is defined differently by different disciplines. Demographers define urbanization as a demographic transition that involves a population becoming urbanized through the increase in the urban proportion of the total population (Montgomery, 2008; Dorélien et al., 2013). Geographers and planners describe urbanization as a land change process that includes the expansion of the urban land cover and growth in built-up areas and infrastructure (Berry et al., 1970; Blanco et al., 2011; Seto et al., 2011). Economists characterize urbanization as a structural shift from primary economic activities such as agriculture and forestry to manufacturing and services (Davis and Henderson, 2003; Henderson, 2003). Sociologists, political scientists, and other social scientists describe urbanization as cultural change, including change in social interactions and the growing complexity of political, social, and economic institutions (Weber, 1966; Berry, 1974). The next sections describe urbanization trends across the first three of these four dimensions and point to the increasing and unprecedented speed and scale of urbanization.

12.2.1.1 Urban population dynamics

In the absence of any other independent data source with global coverage, assessments of historic urban and rural population are commonly based on statistics provided by the United Nations Department for Economic and Social Affairs (UN DESA). The *World Urbanization Prospects* is published every two years by UN DESA and provides projections of key demographic and urbanization indicators for all countries in the world. Even within this dataset, there is no single definition of urban or rural areas that is uniformly applied across the data. Rather, each country develops its own definition of urban, often based a combination of population size or density, and other criteria such as the percentage of population not employed in agriculture; the availability of electricity, piped water, or other infrastructure; and characteristics of the built environment such as dwellings and built structures (UN DESA, 2012). The large variation in criteria gives rise to significant differences in national definitions. However, the underlying variations in the data do not seriously affect an assessment of urbanization dynamics as long as the national definitions are sufficiently consistent over time (GEA, 2012; UN DESA, 2012). Irrespective of definition, the underlying assumption in all the definitions is that urban areas provide a higher standard of living than rural areas (UN DESA, 2013). A comprehensive assessment of urban and rural population dynamics is provided in the Global Energy Assessment (2012). Here, only key developments are briefly summarized.

For most of human history, the world population mostly lived in rural areas and in small urban settlements, and growth in global urban population occurred slowly. In 1800, when the world population was around one billion, only 3% of the total population lived in urban areas and only one city—Beijing—had had a population greater than one million (Davis, 1955; Chandler, 1987; Satterthwaite, 2007). Over the next one hundred years, the global share of urban population increased to 13% in 1900. The second half of the 20th century experienced rapid urbanization. The proportion of world urban population increased from 13% in 1900, to 29% in 1950, to 52% in 2011 (UN DESA, 2012). In 1960, the world reached a milestone when global urban population surpassed one billion (UN DESA, 2012). Although it took all previous human history to 1960 to reach one billion urban dwellers, it took only additional 26 years to reach two billion (Seto et al., 2010). Since then, the time interval to add an additional one billion urban dwellers is decreasing, and by approximately 2030, the world urban population will increase by one billion every 13 years (Seto et al., 2010). Today, approximately 52% of the global population, or 3.6 billion, are estimated to live in urban areas (UN DESA, 2012).

While urbanization has been occurring in all major regions of the world (Table 12.1) since 1950, there is great variability in urban transitions across regions and settlement types. This variability is shaped by multiple factors, including history (Melosi, 2000), migration patterns (Harris and Todaro, 1970; Keyfitz, 1980; Chen et al., 1998), technological development (Tarr, 1984), culture (Wirth, 1938; Ingle hart, 1997), governance institutions (National Research Council, 2003), as well as environmental factors such as the availability of energy (Jones, 2004; Dredge, 2008). Together, these factors partially account for the large variations in urbanization levels across regions.

Table 12.1. Arithmetic growth of human settlement classes for five periods between 1950–2050. Number of human settlements by size class at four points in time.

	Average annual growth [%]					**Number of cities**			
	1950–1970	1970–1990	1990–2010	1950–2010	2010–2050	1950	1970	1990	2010
10,000,000 and more	2.60	6.72	4.11	4.46	2.13	2	2	10	23
5,000,000 – 10,000,000	7.55	1.34	2.53	3.77	1.22	4	15	19	38
1,000,000 – 5,000,000	3.27	3.17	2.70	3.05	1.36	69	128	237	388
100,000–1,000,000	2.86	2.48	1.87	2.40	0.70	Not Available			
Less than 100,000	2.54	2.37	1.71	2.21	1.95				
Rural	1.38	1.23	0.61	1.07	-0.50				

Source: (UN DESA, 2012).

Urbanization rates in developed regions are high, between 73% in Europe to 89% in North America, compared to 45% in Asia and 40% in Africa (UN DESA, 2012).The majority of urbanization in the future is expected to take place primarily in Africa and Asia, and will occur at lower levels of economic development than the urban transitions that occurred in Europe and North America. While its urbanization rate is still lower than that of Europe and the Americas, the urban population in Asia increased by 2.3 billion between 1950 and 2010 (Figure 12.1).

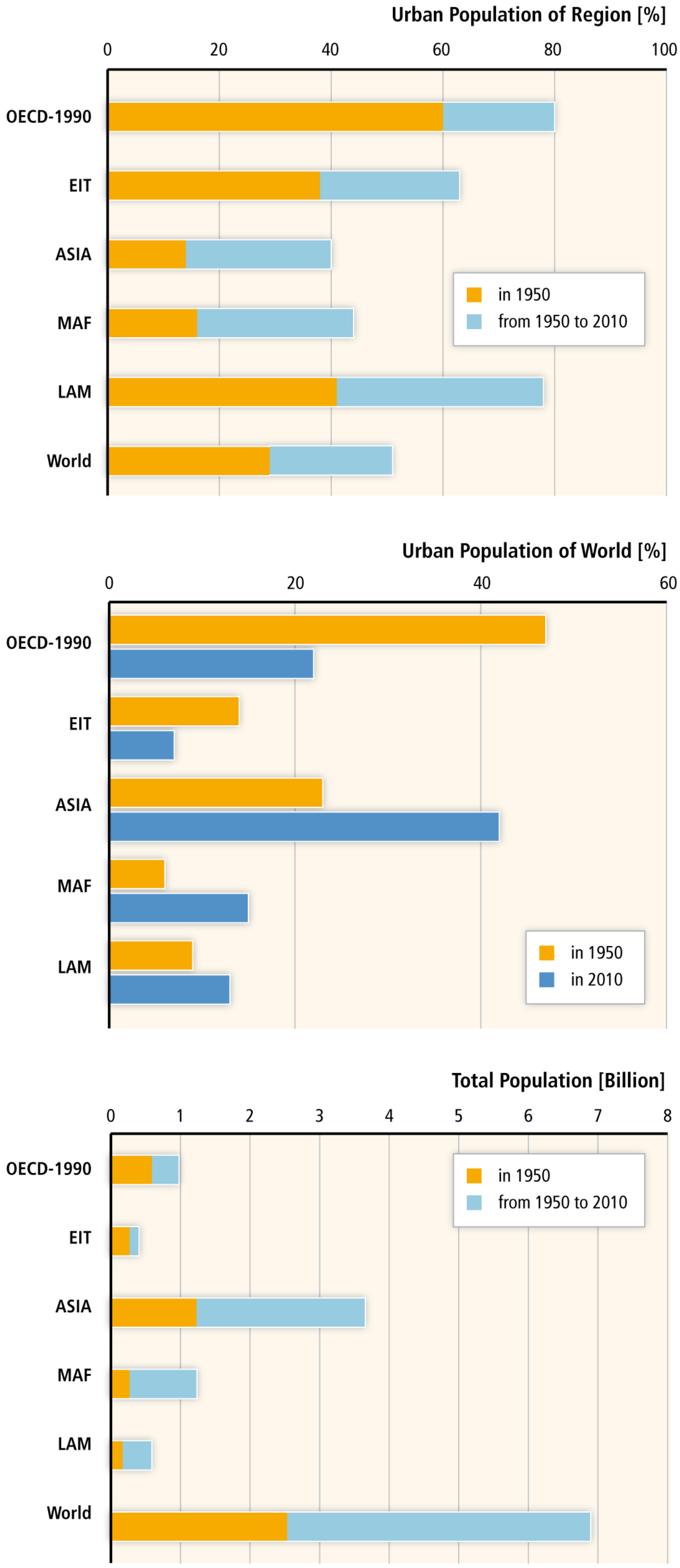

Figure 12.1. Urban population as percentage of regional and world populations and in absolute numbers for RC5 regions (see Annex II.2), 1950-2010 Source: UN DESA, (2012).

Overall, urbanization has led to the growth of cities of all sizes (Figure 12.2). Although mega-cities (those with populations of 10 million or greater) receive a lot of attention in the literature, urban population growth has been dominated by cities of smaller sizes. About one-third of the growth in urban population between 1950 and 2010 (1.16 billion) occurred in settlements with populations fewer than 100 thousand. Currently, approximately 10% of the 3.6 billion urban dwellers live in mega-cities of 10 million or greater (UN DESA, 2012). Within regions and countries, there are large variations in development levels, urbanization processes, and urban transitions. While the dominant global urbanization trend is growth, some regions are experiencing significant urban population declines. Urban shrinkage is not a new phenomenon, and most cities undergo cycles of growth and decline, which is argued to correspond to waves of economic growth and recession (Kondratieff and Stolper, 1935). There are few systematic analyses on the scale and prevalence of shrinking cities (UN-Habitat, 2008). A recent assessment by the United Nations (UN) (UN DESA, 2012) indicates that about 11% of 3,552 cities with populations of 100,000 or more in 2005 experienced total population declines of 10.4 million between 1990 and 2005. These 'shrinking cities' are distributed globally but concentrated mainly in Eastern Europe (Bontje, 2005; Bernt, 2009) and the rust belt in the United States (Martinez-Fernandez et al., 2012), where de-urbanization is strongly tied with de-industrialization.

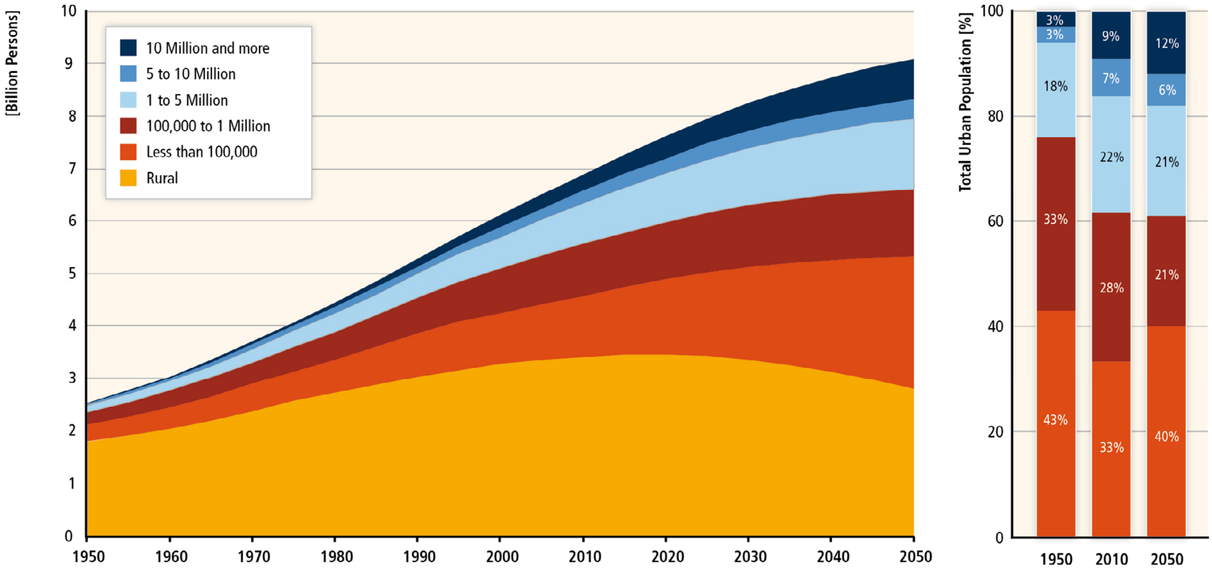

Figure 12.2. Population by settlement size using historical (1950–2010) and projected data to 2050. Source: UN DESA, (2010). Note: rounded population percentages displayed across size classes sum do not sum to 100% for year 2010 due to rounding.

Urbanization results in not only in growth in urban population, but also changes in household structures and dynamics. As societies industrialize and urbanize, there is often a decline in household size, as traditional complex households become more simple and less extended (Bongaarts, 2001; Jiang and O'Neill, 2007; O'Neill et al., 2010). This trend has been observed in Europe and North America, where household size has declined from between four to six in the mid 1800s to between two and three today (Bongaarts, 2001).

12.2.1.2 Urban land use

Another key dimension of urbanization is the increase in built-up area and urban land cover. Worldwide, urban land cover occupies a small fraction of global land surface, with estimates ranging between 0.28 to 3.5 million km^2, or between 0.2% to 2.7% of ice free terrestrial land (Schneider et al., 2009). Although the urban share of global land cover is negligible, urban land use at the local scale shows trends of declining densities and outward expansion.

Analyses of 120 global cities show significant variation in densities across world regions, but the dominant trend is one of declining built-up and population densities across all income levels and city sizes (Figure 12.3) (Angel et al., 2010). For this sample of cities, built-up area densities have declined significantly between 1990 and 2000, at an average annual rate of 2.0±0.4 % (Angel et al., 2010). On average, urban population densities are four times higher in low-income countries (11,850 persons/km^2 in 2000) than in high-income countries (2,855 persons/km^2 in 2000). Urban areas in Asia experienced the largest decline in population densities during the 1990s. Urban population densities in East Asia and Southeast Asia declined 4.9% and 4.2%, respectively, between 1990 and 2000 (World Bank, 2005). These urban population densities are still higher than those 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 their urban population densities will continue to decline. Although urban population densities are decreasing, the amount of built-up area per person is increasing (Seto et al., 2010; Angel et al., 2011). A meta-analysis of 326 studies using satellite data shows a minimum global increase in urban land area of 58,000km^2 between 1970 and 2000, or roughly 9% of the 2000 urban extent (Seto et al., 2011). At current rates of declining densities among developing country cities, a doubling of the urban population over the next 30 years will require a tripling of built-up areas (Angel et al., 2010). For a discussion on drivers of declining densities, see Box 12.4.

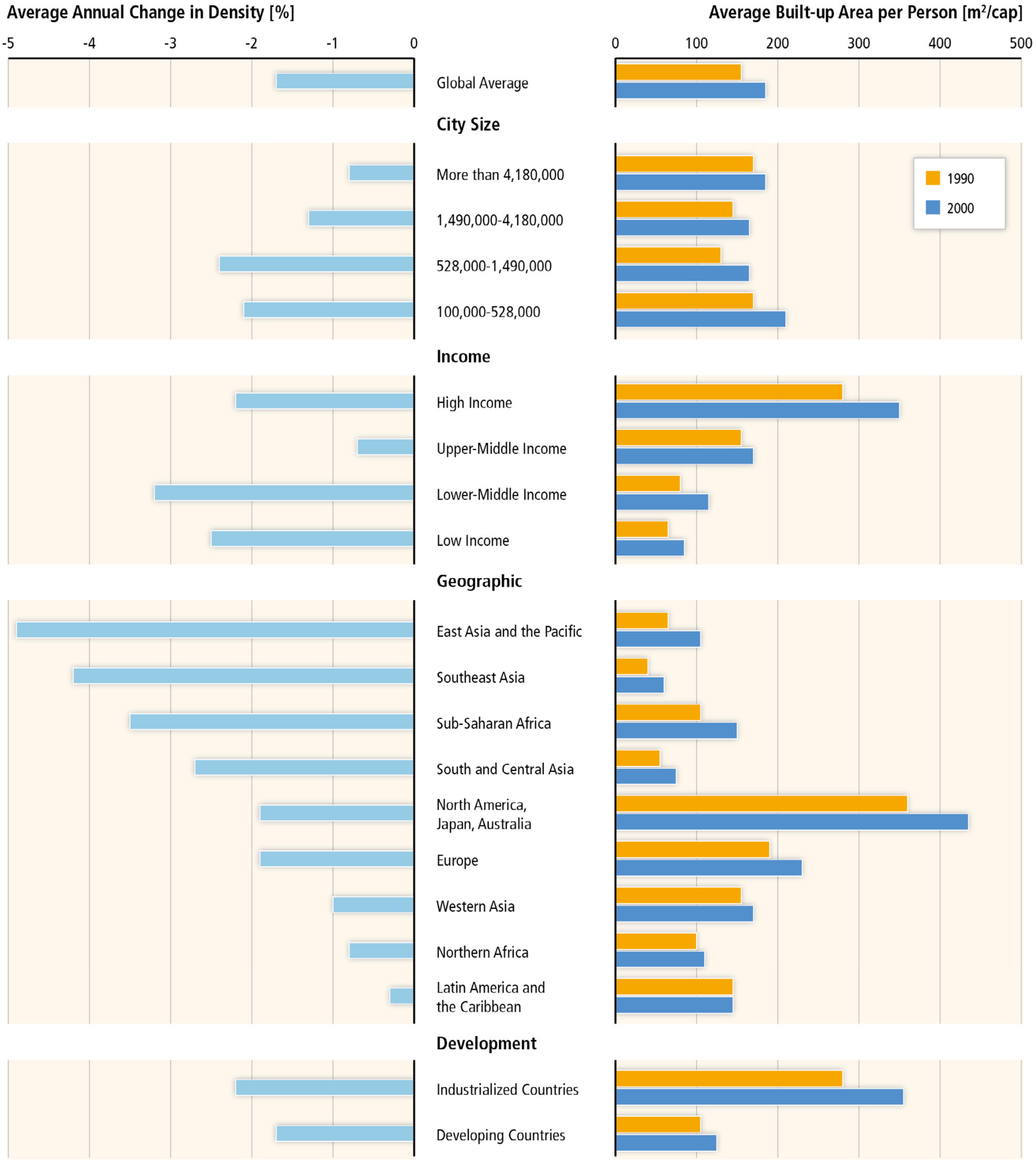

Figure 12.3. Average built-up area per person (m^2) in 1990 (yellow) and 2000 (blue) for 120 cities. Average annual percent change in density (light blue). Source: Angel et al., (2005).

12.2.1.3 Urban economies and GDP

Urban areas are engines of economic activities and growth. Further, the transition from a largely agrarian and rural society to an industrial and consumption-based society is largely coincident with a country's level of industrialization and economic development (Tisdale 1942; Jones 2004), and reflects changes in the relative share of GDP by both sector and the proportion of the labour force employed in these sectors (Satterthwaite, 2007; World Bank, 2009). The concentration and scale of people, activities, and resources in urban areas fosters economic growth (Henderson et al., 1995; Fujita and Thisse, 1996; Duranton and Puga, 2004; Puga, 2010), innovation (Feldman and Audretsch, 1999; Bettencourt et al., 2007; Arbesman et al., 2009), and an increase of economic and resource use efficiencies (Kahn, 2009; Glaeser and Kahn, 2010). The agglomeration economies made possible by the concentration of individuals and firms make cities ideal settings for innovation, job, and wealth creation (Rosenthal and Strange, 2004; Carlino et al., 2007; Knudsen et al., 2008; Puga, 2010).

A precise estimate of the contribution of all urban areas to global GDP is not available. However, a downscaling of global GDP during the Global Energy Assessment (Grubler et al., 2007; GEA, 2012) showed that urban areas contribute about 80% of global GDP. Other studies show that urban economies generate more than 90% of global gross value (Gutman, 2007; United Nations, 2011). In OECD countries, more than 80% of the patents filed are in cities (OECD, 2006a). Not many cities report city-level GDP but recent attempts have been made by the Metropolitan Policy Program of the Brookings Institute, PriceWaterhouseCoopers (PWC), and the McKinsey Global Institute to provide such estimates. The PWC report shows that key 27 key global cities[1] accounted for 8% of world GDP for 2012 but only 2.5% of the global population (PwC and Partnership for New York City, 2012).

In a compilation by UN-Habitat, big cities are shown to have disproportionately high share of national GDP compared to their population (UN-Habitat, 2012). The importance of big cities is further underscored in a recent report that shows that 600 cities generated 60% of global GDP in 2007 (McKinsey Global Institute, 2011). This same report shows that the largest 380 cities in developed countries account for half of the global GDP. More than 20% of global GDP comes from 190 North American cities alone (McKinsey Global Institute, 2011). In contrast, the 220 largest cities in developing countries contribute to only 10% global of GDP, while 23 global megacities generated 14% of global GDP in 2007. The prevalence of economic concentration in big cities highlights their importance but does not undermine the role of small and medium size cities. Although top-down and bottom-up estimates suggest a large urban contribution to global GDP, challenges remain in estimating the size of this, given large uncertainties in the downscaled GDP, incomplete urban coverage, sample bias, methodological ambiguities, and limitations of the city-based estimations in the existing studies.

12.2.2 GHG emission estimates from human settlements

Most of the literature on human settlements and climate change is rather recent.[2] Since AR4, there has been a considerable growth in scientific evidence on energy consumption and GHG emissions from human settlements. However, there are very few studies that have examined the contribution of all urban areas to global GHG emissions. The few studies that do exist will be discussed in Section

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[1] Paris, Hong Kong, Sydney, San Francisco, Singapore, Toronto, Berlin, Stockholm, London, Chicago, Los Angeles, New York, Tokyo, Abu Dhabi, Madrid, Kuala Lumpur, Milan, Moscow, São Paulo, Beijing, Buenos Aires, Johannesburg, Mexico City, Shanghai, Seoul, Istanbul, and Mumbai.

[2] A search on the ISI Web of Science database for keywords "urban AND climate change" for the years 1900-2007 yielded over 700 English language publications. The same search for the period from 2007 to present yielded nearly 2800 English language publications.

12.2.2.1. In contrast, a larger number of studies have quantified GHG emissions for individual cities and other human settlements. These will be assessed in Section 12.2.2.2.

12.2.2.1 Estimates of the urban share of global emissions

There are very few studies that estimate the relative urban and rural shares of global GHG emissions. One challenge is that of boundary definitions and delineation: it is difficult to consistently define and delineate rural and urban areas globally (see Box 12.1). Another challenge is that of severe data constraints about GHG emissions. There is no comprehensive statistical database on urban or rural GHG emissions. Available global estimates of urban and rural emission shares are either derived bottom-up or top-down. Bottom-up, or up-scaling studies, use a representative sample of estimates from regions or countries and scale these up to develop world totals (see International Energy Agency, 2008). Top-down studies use global or national datasets and downscale these to local grid cells. Urban and rural emissions contributions are then estimated based on additional spatial information such as the extent of urban areas or the location of emission point sources (GEA, 2012). In the absence of a more substantive body of evidence, large uncertainties remain surrounding the estimates and their sensitivities (Grubler et al., 2012).

The *World Energy Outlook 2008* estimates urban energy related CO_2 emissions at 19.8 Gt, or 71% of the global total for the year 2006 (International Energy Agency, 2008). This corresponds to 330 EJ of primary energy, of which urban final energy use is estimated to be at 222 EJ. The Global Energy Assessment provides a range of final urban energy use between 180 and 250 EJ with a central estimate of 240 EJ for the year 2005. This is equivalent to an urban share between 56% and 78% (central estimate, 76%) of global final energy use. Converting the GEA estimates on urban final energy (Grubler et al., 2012) into CO_2 emissions (see Methodology and Metrics Annex) results in global urban energy related CO_2 emissions of 8.8 – 14.3 Gt (central estimate, 12.5Gt) which is between 53% and 87% (central estimate, 76%) of CO_2 emissions from global final energy use and between 30% and 56% (central estimate, 43%) of global primary energy related CO_2 emissions (CO_2 includes flaring and cement emissions which are small). Urban CO_2 emission estimates refer to commercial final energy fuel use only and exclude upstream emissions from energy conversion.

Aside from these global assessments, there is only one attempt in the literature to estimate the total GHG (CO_2, CH_4, N_2O and SF_6) contribution of urban areas globally (Marcotullio et al., 2013). Estimates are provided in ranges where the lower end provides an estimate of the direct emissions from urban areas only and the higher end provides an estimate that assigns all emissions from electricity consumption to the consuming (urban) areas. Using this methodology, the estimated total GHG emission contribution of all urban areas is lower than other approaches, and ranges from 12.8 $GtCO_{2eq}$ to 16.9 $GtCO_{2eq}$, or between 37% and 49% of global GHG emissions in the year 2000. The estimated urban share of energy related CO_2 emissions in 2000 is slightly lower than the GEA and IEA estimate, at 72% using Scope 2 accounting and 44% using Scope 1 accounting (see Figure 12.4). The urban GHG emissions (CO_2, N_2O, CH_4, and SF_6) from the energy share of total energy GHGs is between 42% and 66%. Hence, while the sparse evidence available suggests that urban areas dominate final energy consumption and associated CO_2 emissions, the contribution to total global GHG emissions may be more modest as the large majority of CO_2 emissions from land-use change, N_2O emissions, and CH_4 emissions take place outside urban areas.

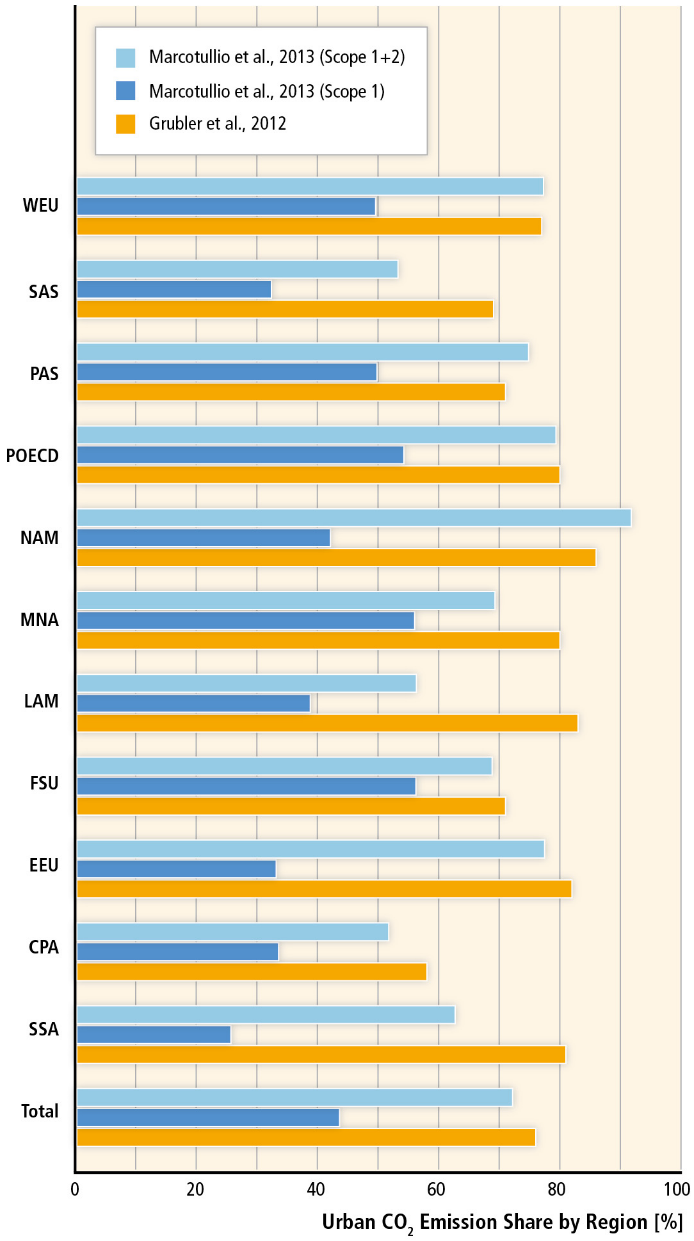


Figure 12.4. Estimates of urban CO_2 emissions shares as a percent of total emissions across world regions. Grübler et al. (2012) estimates are based on estimates of final urban and total final energy use in 2005. Marcotullio et al. (2013) estimates are based on emissions attributed to urban areas as a percent of regional totals reported by EDGAR. Scope 2 emissions allocate all emissions from thermal power plants to urban areas.

Figure 12.4 shows CO_2 estimates derived from Grübler et al. (2012) and Marcotullio et al. (2013). It highlights that there are large variations in the share of urban CO_2 emissions across world regions. For example, urban emission shares of final energy related CO_2 emissions range from 58% in China and Central Pacific Asia to 86% in North America. Ranges are from 31%to 57% in South Asia, if urban final energy related CO_2 emissions are taken relative to primary energy related CO_2 emissions in the respective region.

Although differences in definitions make it challenging to compare across regional studies, there is consistent evidence that large variations exist (Parshall et al., 2010; Marcotullio et al., 2011, 2012). For example, the International Energy Agency (IEA) (2008) estimates of the urban primary energy related CO_2 emission shares are 69% for the EU (69% for primary energy), 80% for the United States (85% for primary energy, see also (Parshall et al., 2010), and 86% for China (75% for primary energy, see also (Dhakal, 2009)). Marcotullio et al. (2013) highlight that non-energy related sectors can lead to substantially different urban emissions shares under consideration of a broader selection of greenhouse gases (CO_2, CH_4, N_2O, SF_6). For example, while Africa tends to have a high urban CO_2 emissions share (64%–74%) in terms of energy related CO_2 emissions, the overall contribution of urban areas across all sectors and gases is estimated to range between 21% and 30% of all emissions (Marcotullio et al., 2013).

12.2.2.2 Emissions accounting for human settlements

Whereas the previous section discussed the urban proportion of total global emissions, this section assesses emissions accounting methods for human settlements. A variety of emission estimates have been published by different research groups in the scientific literature (e.g.,Ramaswami et al., 2008; Kennedy et al., 2009, 2011; Dhakal, 2009; World Bank, 2010; Hillman and Ramaswami, 2010; Glaeser and Kahn, 2010; Sovacool and Brown, 2010; Heinonen and Junnila, 2011a; c; Hoornweg et al., 2011; Chavez and Ramaswami, 2011; Chavez et al., 2012; Grubler et al., 2012; Yu et al., 2012; Chong et al., 2012). The estimates of GHG emissions and energy consumption for human settlements are very diverse. Comparable estimates are usually only available across small samples of human settlements, which currently limit the insights that can be gained from an assessment of these estimates. The limited number of comparable estimates is rooted in the absence of commonly accepted GHG accounting standards and a lack of transparency over data availabilities, as well as choices that have been made in the compilation of particular estimates:

- **Choice of physical urban boundaries.** Human settlements are open systems with porous boundaries. Depending on how physical boundaries are defined, estimates of energy consumption and GHG emissions can vary significantly (see Box 12.1).
- **Choice of accounting approach/reporting scopes**. There is widespread acknowledgement in the literature for the need to report beyond the direct GHG emissions released from within a settlement’s territory. Complementary accounting approaches have therefore been proposed to characterize different aspects of the GHG performance of human settlements (see Box 12.2). Cities and other human settlements are increasingly adopting dual approaches (Baynes et al., 2011; Ramaswami et al., 2011; ICLEI and WRI, 2012; Carbon Disclosure Project, 2013; Chavez and Ramaswami, 2013).
- **Choice of calculation methods**. There are differences in the methods used for calculating emissions, including differences in emission factors used, methods for imputing missing data, and methods for calculating indirect emissions (Heijungs and Suh, 2010; Ibrahim et al., 2012).

A number of organizations have started working towards standardization protocols for emissions accounting (Carney et al., 2009; ICLEI, 2009; Covenant of Mayors, 2010; UNEP et al., 2010; Arikan, 2011). Further progress has been achieved recently when several key efforts joined forces to create a more broadly supported reporting framework (ICLEI et al., 2012). Ibrahim et al. (2012) show that the differences across reporting standards explains significant cross-sectional variability in reported emission estimates. However, while high degrees of cross-sectional comparability are crucial in order to gain further insight into the emission patterns of human settlements across the world, many applications at the settlement level do not require this. Cities and other localities often compile these data to track their own performance in reducing energy consumption and/or greenhouse gas emissions (see Section 12.7). This makes a substantial body of evidence difficult to use for scientific inquiries.

Box 12.2. Emission accounting at the local scale

Three broad approaches have emerged for GHG emissions accounting for human settlements, each of which uses different boundaries and units of analysis.

1) Territorial or production-based emissions accounting includes all GHG emissions from activities within a city or settlement's territory (see Box 12.1). This is also referred to as Scope 1 accounting (Kennedy et al., 2010; ICLEI et al., 2012). Territorial emissions accounting is, for example, commonly applied by national statistical offices and used by countries under the United Nations Framework Convention on Climate Change (UNFCCC) for emission reporting (Ganson, 2008; DeShazo and Matute, 2012; ICLEI et al., 2012).

However, human settlements are typically smaller than the infrastructure in which they are embedded, and important emission sources may therefore be located outside the city territorial boundary. Moreover, human settlements trade goods and services that are often produced in one settlement but are consumed elsewhere, thus creating GHG emissions at different geographic locations associated with the production process of these consumable items. Two further approaches have thus been developed in the literature, as noted below.

2) Territorial plus supply chain accounting approaches start with territorial emissions and then add a well defined set of indirect emissions which take place outside the settlement's territory. These include indirect emissions from (1) the consumption of purchased electricity, heat and steam (Scope 2 emissions), and (2) any other activity (Scope 3 emissions). The simplest and most frequently used territorial plus supply chain accounting approach includes Scope 2 emissions (Hillman and Ramaswami, 2010; Kennedy et al., 2010; Baynes et al., 2011; ICLEI et al., 2012).

3) Consumption-based accounting approaches include all direct and indirect emissions from final consumption activities associated with the settlement, which usually include consumption by residents and government (Larsen and Hertwich, 2009, 2010a; b; Heinonen and Junnila, 2011a; b; Jones and Kammen, 2011; Minx et al., 2013). This approach excludes all emissions from the production of exports in the settlement territory and includes all indirect emissions occurring outside the settlement territory in the production of the final consumption items.

Beyond the restricted comparability of the available GHG estimates, six other limitations of the available literature remain. First, the growth in publications is restricted to the analysis of energy consumption and GHG emissions from a limited set of comparable emission estimates. New estimates do not emerge at the same pace. Second, available evidence is particularly scarce for medium and small cities as well as rural settlements (Grubler et al., 2012). Third, there is a regional bias in the evidence. Most studies focus on emissions from cities in developed countries with limited evidence from a few large cities in the developing world (Kennedy et al., 2009, 2011; Hoornweg et al., 2011; Sugar et al., 2012). Much of the most recent literature provides Chinese evidence (Dhakal, 2009; Ru et al., 2010; Chun et al., 2011; Wang et al., 2012a; b; Chong et al., 2012; Yu et al., 2012; Guo et al., 2013; Lin et al., 2013; Vause et al., 2013; Lu et al., 2013), but only limited new emission estimates are emerging from that. Evidence on human settlements in least developed countries is almost non-existent with some notable exceptions in the non peer-reviewed literature (Lwasa, 2013). Fourth, most of the available emission estimates are focusing on energy related CO_2 rather than all GHG emissions. Fifth, while there is a considerable amount of evidence for territorial emissions, studies that include Scope 2 and 3 emission components are growing but remain limited (Ramaswami et al., 2008, 2012b; Kennedy et al., 2009; Larsen and Hertwich, 2009, 2010a; b; Hillman and Ramaswami, 2010; White et al., 2010; Petsch et al., 2011; Heinonen and Junnila, 2011a; b; Heinonen et al., 2011; Chavez et al., 2012; Paloheimo and Salmi, 2013; Minx et al., 2013). Finally, the comparability of available evidence of GHG emissions at the city scale is usually restricted across studies. There prevails marked differences in terms of the accounting methods, scope of covered sectors, sector definition, greenhouse gas covered, and data sources used (Bader and Bleischwitz, 2009; Kennedy et al., 2010; Chavez and Ramaswami, 2011; Grubler et al., 2012; Ibrahim et al., 2012).

Across cities, existing studies point to a large variation in the magnitude of total and per capita emissions. For this assessment, emission estimates for several hundred individual cities were reviewed. Reported emission estimates for cities and other human settlements in the literature range from 0.5 tCO_2/cap to more than 190 tCO_2/cap (Carney et al., 2009; Kennedy et al., 2009; Dhakal, 2009; Heinonen and Junnila, 2011a; c; Wright et al., 2011; Sugar et al., 2012; Ibrahim et al., 2012; Ramaswami et al., 2012b; Carbon Disclosure Project, 2013; Chavez and Ramaswami, 2013; Department of Energy & Climate Change, 2013). Local emission inventories in the UK for 2005–2011 show that end use activities and industrial processes of both rural and urban localities vary from below 3 to 190 tCO_2/cap and more (Department of Energy & Climate Change, 2013). The total CO_2 emissions from end use activities for ten global cities range (reference year ranges 2003–2006) between 4.2 and 21.5 tCO_2eq/cap (Kennedy et al., 2009; Sugar et al., 2012), while there is variation reported in GHG estimates from 18 European city regions from 3.5 to 30 tCO_2eq/cap in 2005 (Carney et al., 2009).

In many cases, a large part of the observed variability will be related to the underlying drivers of emissions such as urban economic structures (balance of manufacturing versus service sector), local climate and geography, stage of economic development, energy mix, state of public transport, urban form and density, and many others (Carney et al., 2009; Kennedy et al., 2009, 2011; Dhakal, 2009, 2010; Glaeser and Kahn, 2010; Shrestha and Rajbhandari, 2010; Gomi et al., 2010; Parshall et al., 2010; Rosenzweig et al., 2011; Sugar et al., 2012; Grubler et al., 2012; Wiedenhofer et al., 2013). Normalizing aggregate city-level emissions by population therefore does not necessarily result in robust cross-city comparisons, since each city's economic function, trade typology, and imports-exports balance can differ widely. Hence, using different emissions accounting methods can lead to substantial differences in reported emissions (see Figure 12.4). Therefore, understanding differences in accounting approaches is essential in order to draw meaningful conclusions from cross-city comparisons of emissions.

Evidence from developed countries such as the United States, Finland, or the United Kingdom suggests that consumption-based emission estimates for cities and other human settlements tend to be higher than their territorial emissions. However, in some cases, territorial or extended territorial emission estimates (Scope 1 and Scope 2 emissions) can be substantially higher. This is mainly due to the large fluctuations in territorial emission estimates that are highly dependent on a city's economic structure and trade typology. Consumption-based estimates tend to be more homogenous (see Figure 12.5).

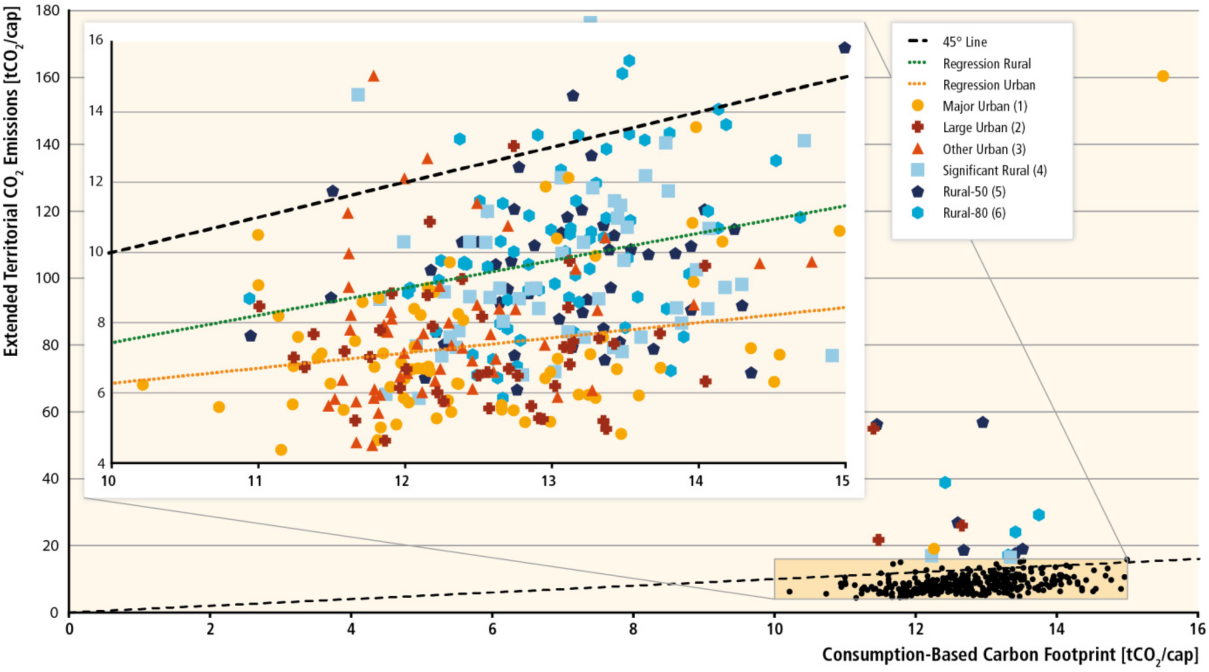


Figure 12.5. Extended territorial and consumption-based per capita CO_2 emissions for 354 urban (yellow/orange/red) and rural (blue) municipalities in England. At the 45° line, per capita extended territorial and consumption-based CO_2 emissions are of equal size. Below the 45° line, consumption-based CO_2 emission estimates are larger than extended territorial emissions. Above the 45° line, estimates of extended territorial CO_2 emissions are larger than consumption-based CO_2 emissions. Robust regression lines are shown for the rural (blue) and urban (yellow/orange/red) sub-samples. In the inset, the x-axis shows 10–15 tonnes of CO_2 emissions per capita and the y-axis shows 4–16 tonnes of CO_2 emissions per capita. Source: Minx et al., (2013).

Based on a global sample of 198 cities by the Global Energy Assessment, Grubler et al. (2012) find that two out of three cities in Annex I countries have a lower per capita final energy use than national levels. In contrast, per capita final energy use for more than two out of three cities in non-Annex I countries have higher than national averages (see Figure 12.6). There is not sufficient comparable evidence available for this assessment to confirm this finding for energy related CO_2 emissions, but this pattern is suggested by the close relationship between final energy use and energy related CO_2 emissions. Individual studies for 35 cities in China, Bangkok, and 10 global cities provide additional evidence of these trends (Dhakal, 2009; Aumnad, 2010; Kennedy et al., 2010; Sovacool and Brown, 2010). Moreover, the literature suggests that differences in per capita energy consumption and CO_2 emission patterns of cities in Annex I and non-Annex I countries have converged more than their national emissions (Sovacool and Brown, 2010; Sugar et al., 2012). For consumption-based CO_2 emissions, initial evidence suggests that urban areas tend to have much higher emissions than rural areas in non-Annex I countries, but the evidence is limited to a few studies on India and China (Parikh and Shukla, 1995; Guan et al., 2008, 2009; Pachauri and Jiang, 2008; Minx et al., 2011). For Annex I countries, studies suggest that using consumption based CO_2 emission accounting, urban areas can, but do not always, have higher emissions than rural settlements (Lenzen et al., 2006; Heinonen and Junnila, 2011c; Minx et al., 2013).

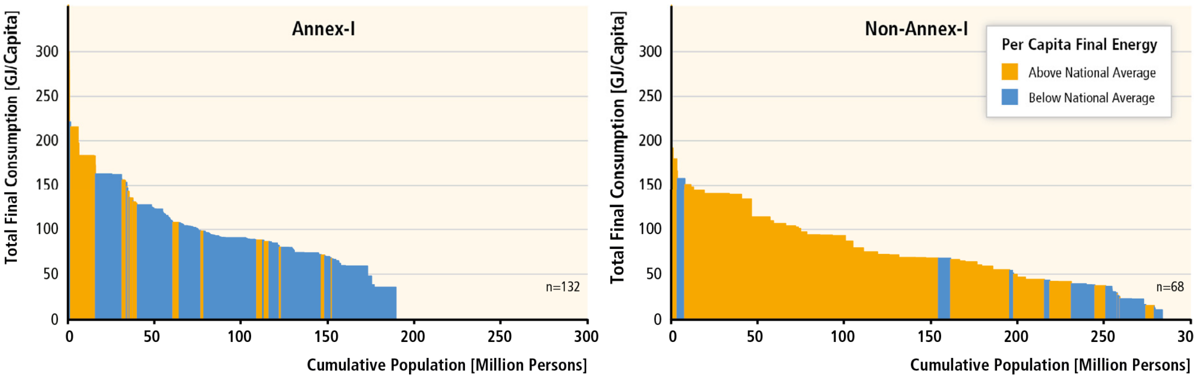


Figure 12.6. Per capita (direct) total final consumption (TFC) of energy (GJ) versus cumulative population (millions) in urban areas. Source: GEA, (2012).

There are only a few downscaled estimates of CO_2 emissions from human settlements and urban as well as rural areas, mostly at regional and national scales for the EU, United States, China, and India (Parshall et al., 2010; Raupach et al., 2010; Marcotullio et al., 2011, 2012; Gurney et al., 2012). However, these studies provide little to no representation of intra-urban features and therefore cannot be substitutes for place-based emission studies from cities. Recent studies have begun to combine downscaled estimates of CO_2 emissions with local urban energy consumption information to generate fine-scale maps of urban emissions (see Figure 12.7 and Gurney et al., 2012). Similarly, geographic-demographic approaches have been used for downscaling consumption-based estimates (Druckman and Jackson, 2008; Minx et al., 2013). Such studies may allow more detailed analyses of the drivers of urban energy consumption and emissions in the future.

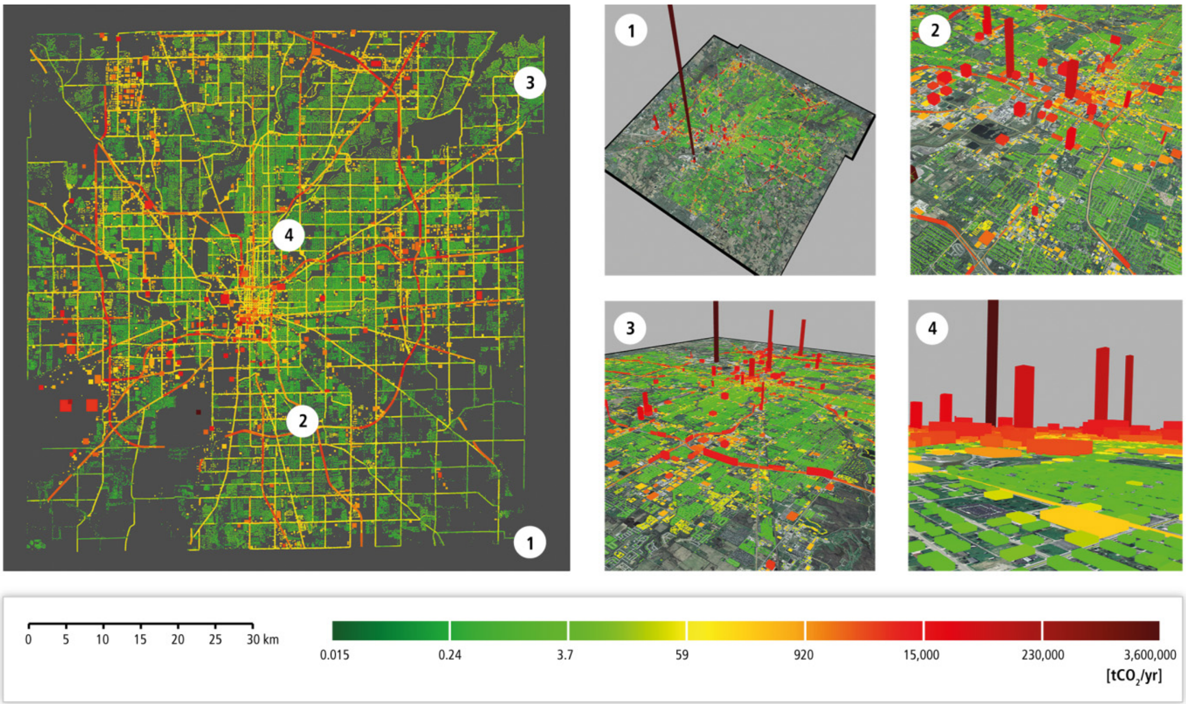


Figure 12.7. Total fossil fuel emissions of Marion County, Indiana, USA, for the year 2002. a) top-down view with numbered zones and b) blow ups of numbered zones. Box height units: linear. Source: Gurney et al., (2012).

12.2.3 Future trends in urbanization and GHG emissions from human settlements

This section addresses two issues concerning future scenarios of urbanization. It summarizes projected future urbanization dynamics in multiple dimensions. It assesses and contextualizes scenarios of urban population growth, urban expansion, and urban emissions.

12.2.3.1 Dimension 1: Urban population

Worldwide, populations will increasingly live in urban settlements. By the middle of the century, the global urban population is expected to reach between 5.6 to 7.1 billion, with trends growth varying substantially across regions (Table 12.2). While highly urbanized North America, Europe, Oceania, and Latin America will continue to urbanize, the increase in urbanization levels in these regions is relatively small. Urbanization will be much more significant in Asia and Africa where the majority of the population is still rural. Urban population growth will also largely occur in the less developed Africa, Asia, and Latin America. The proportion of rural population in the developed regions have declined from about 60% in 1950 to less than 30% in 2010, and will continue to decline to less than 20% by 2050.

Table 12.2. Mid-year global urban population, 2050

2050 Mid-Year Global Urban Population			
Source	Total Pop. *in billions*	% Urban	Urban Pop. *in billions*
IIASA Greenhouse Gas Index, A2R Scenario	10.245	69	7.069
World Bank	9.417	67	6.308
United Nations	9.306	67	6.252
IIASA Greenhouse Gas Index, B2 Scenario	9.367	66	6.182
IIASA Greenhouse Gas Index, B1 Scenario	8.721	64	5.581

Sources: (IIASA, 2009; UN DESA, 2012; World Bank, 2013).

Uncertainties in future global urbanization trends are large, due in part to different trajectories in economic development and population growth. While the United Nations Development Programme (UNPD) produces a single urbanization scenario for each country through 2050, studies suggests that urbanization processes in different countries and different periods of time vary remarkably. Moreover, past UN urbanization projections have contained large errors and have tended to overestimate urban growth, especially for countries at low and middle urbanization levels (Bocquier, 2005; Montgomery, 2008; Alkema et al., 2011).

Given these limitations, recent studies have begun to explore a range of urban population growth scenarios. A study undertaken at International Institute for Applied Systems Analysis (IIASA) extrapolates UN scenarios to 2100 and develops three alternative scenarios by making assumptions about long-term maximum urbanization levels (Grubler et al., 2007). However, missing from these scenarios is the full range of uncertainty over the next twenty to thirty years, the period when the majority of developing countries will undergo significant urban transitions. For instance, variation across different urbanization scenarios before 2030 is negligible (0.3%) for India and also very small (<4%) for China (see Figure 12.8, dashed lines). By 2050, urbanization levels could realistically reach between 38–69% in India, and 55–78% in China (O'Neill et al., 2012). In other words, there are large uncertainties in urbanization trajectories for both countries. The *speed* (fast or slow) as well as the *nature* (an increase in industrialization) of urbanization could lead to significant effects on future urban energy use and emissions.

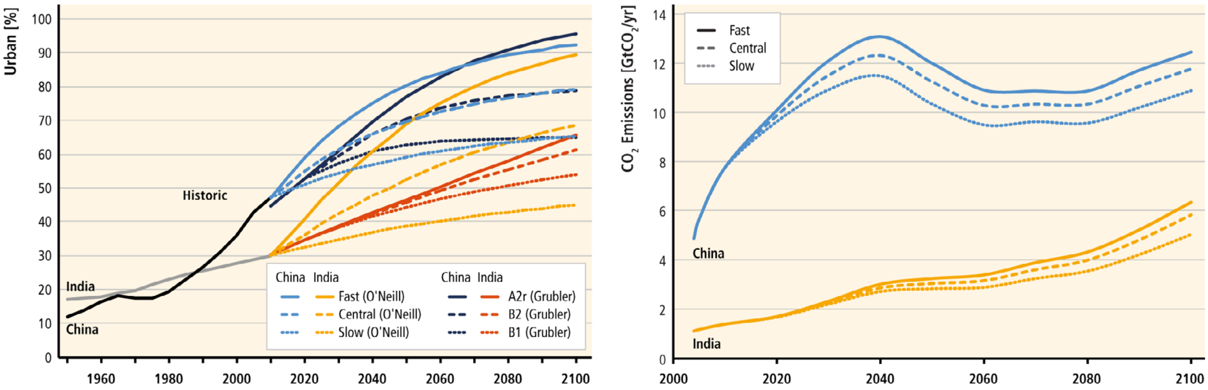


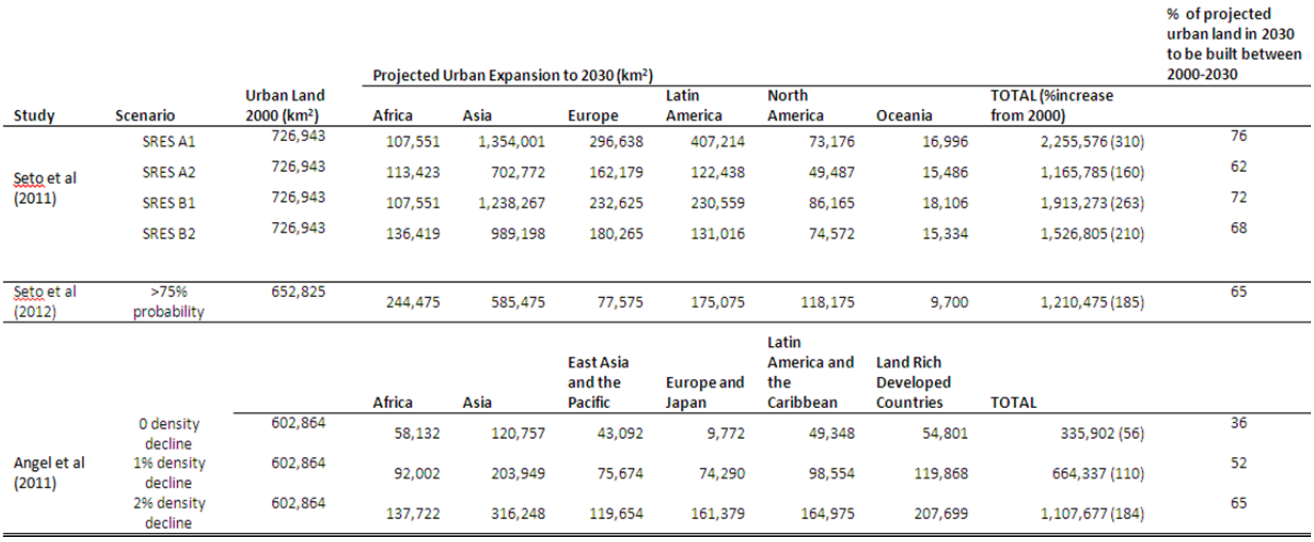
Figure 12.8. Projected urban population growth for India and China under fast, central, and slow growth scenarios (left) and associated growth in CO_2 emissions (right). Sources: (O'Neill et al., 2012), (Grubler et al., 2007).

12.2.3.2 Dimension 2: Urban land cover

Recently, global forecasts of urban expansion that take into account population and economic factors have become available (Nelson et al., 2010; Angel et al., 2011; Seto et al., 2011, 2012). These studies vary in their baseline urban extent in 2000, model inputs, assumptions about future trends in densities, economic and population growth, and modelling methods. They forecast that between 2000 and 2030, urban areas will expand between 0.3 million to 2.3 million km^2, corresponding to an increase between 56% to 310% (see Table 12.3 and Angel et al., 2011; Seto et al., 2011, 2012). It is important to note that these studies forecast changes in urban land cover (features of Earth's surface) and not changes in the built environment and infrastructure (e.g., buildings, roads). However, these forecasts of urban land cover can be useful to project infrastructure development and associated emissions. Given worldwide trends of declining densities, the zero population density decline scenario and associated urban growth forecast (0.3 million) is unlikely, as is the *Special Report on Emissions Scenarios* (SRES) A1 scenario of very rapid economic growth and a peak in global population mid-century. According to the studies, the most likely scenarios are SRES B2 (Seto et al., 2011), >75% probability (Seto et al., 2012), and 2% decline (Angel et al., 2011), which reduces the range of forecast estimates to between 1.1 to 1.5 million km^2 of new urban land. This corresponds to an increase in urban land cover between 110% to 210% over the 2000 global urban extent. Hurtt et al. (2011) report projected land-use transitions including urbanization, out to 2100, for the intended use in Earth System Models (ESMs). However, they do not give a detailed account of the projected urban expansion in different parts of the world.

Depending on the scenario and forecast, 55% of the total urban land in 2030 is expected to be built in the first three decades of the 21st century. Nearly half of the global growth in urban land cover is forecasted to occur in Asia, and 55% of the regional growth will take place in China and India (Seto et al., 2012). China's urban land area is expected to expand by almost 220,000 square km^2 by 2030, and account for 18% of the global increase in urban land cover (Seto et al., 2012). These forecasts provide first-order estimates of the likelihood that expansion of urban areas will occur in areas of increasing vulnerability to extreme climate events including floods, storm surges, sea level rise, droughts, and heat waves (See AR5 WGII, Chapter 8). Urban expansion and associated land clearing and loss of aboveground biomass carbon in the pan-tropics is expected to be 1.38 PgC between 2000 and 2030, or 0.05 PgC/yr (Seto et al., 2012).

Table 12.3. Forecasts of global urban land expansion to 2030



			Projected Urban Expansion to 2030 (km^2)							% of projected urban land in 2030 to be built between 2000-2030
Study	Scenario	Urban Land 2000 (km^2)	Africa	Asia	Europe	Latin America	North America	Oceania	TOTAL (%increase from 2000)	
Seto et al (2011)	SRES A1	726,943	107,551	1,354,001	296,638	407,214	73,176	16,996	2,255,576 (310)	76
	SRES A2	726,943	113,423	702,772	162,179	122,438	49,487	15,486	1,165,785 (160)	62
	SRES B1	726,943	107,551	1,238,267	232,625	230,559	86,165	18,106	1,913,273 (263)	72
	SRES B2	726,943	136,419	989,198	180,265	131,016	74,572	15,334	1,526,805 (210)	68
Seto et al (2012)	>75% probability	652,825	244,475	585,475	77,575	175,075	118,175	9,700	1,210,475 (185)	65
			Africa	Asia	East Asia and the Pacific	Europe and Japan	Latin America and the Caribbean	Land Rich Developed Countries	TOTAL	
Angel et al (2011)	0 density decline	602,864	58,132	120,757	43,092	9,772	49,348	54,801	335,902 (56)	36
	1% density decline	602,864	92,002	203,949	75,674	74,290	98,554	119,868	664,337 (110)	52
	2% density decline	602,864	137,722	316,248	119,654	161,379	164,975	207,699	1,107,677 (184)	65

Sources: Angel et al., (2011); Seto et al., (2011), (2012).

12.2.3.3 Dimension 3: GHG emissions

Recent developments in integrated models are beginning to capture the interdependence among urban population, urban land cover, and GHG emissions. Some integrated models have found that changes in urbanization in China and India have a less than proportional effect on aggregate emissions and energy use (O'Neill et al., 2012). These studies find that income effects due to economic growth and urbanization result in household consumption shifts toward cleaner cooking fuels (O'Neill et al., 2012). In India, the urbanization level in 2050 will be 16 percentage points lower under the slow urbanization scenario than under the central scenario, or 15 percentage points higher under the fast scenario than under the central scenario. However, these large differences in potential urbanization levels in India lead to relatively small differences in emissions: 7% between the slow and central urbanization scenarios, and 6% between the fast and central urbanization scenarios (O'Neill et al., 2012). The relatively small effect of urbanization on emissions is likely due to relatively small differences in per capita income between rural and urban areas (O'Neill et al., 2012). In contrast, large differences in per capita income between urban and rural areas in China result in significant differences in household consumption, including for energy (O'Neill et al., 2012). Differences in urbanization pathways also reflect different speeds of transition away from the use of traditional fuels toward modern fuels such as electricity and natural gas (Krey et al., 2012). Slower rates of urbanization result in slower transitions away from traditional to modern fuels (Jiang and O'Neill, 2004; Pachauri and Jiang, 2008). A large share of solid fuels or traditional biomass in the final energy mix can have adverse health impacts due to indoor air pollution (Bailis et al., 2005; Venkataraman et al., 2010).

Accounting for uncertainties in urban population growth, the scenarios show that urbanization as a demographic process does not lead to a corresponding growth in emissions and energy use (Figure 12.8b). In China, for example, under the central scenario (similar to UN projections) the country will reach 70% urban population by 2050 and the total carbon emissions will reach 11 GtC/yr. Under the slow urbanization scenario, the urbanization level is 13% lower than the central urbanization scenario, but results in emissions that are 9% lower than under the central urbanization scenario. Similarly, the fast urbanization scenario results in emissions that are 7% higher than under the central scenario, but with urbanization levels that are 11% higher.

Studies of the effects of demographic change on GHG emissions come to contradicting conclusions (Dalton et al., 2008; Kronenberg, 2009). Many of the forecasts on urbanization also do not explicitly account for the infrastructure for which there is a separate set of forecasts (Davis et al., 2010;

Kennedy and Corfee-Morlot, 2013; Müller et al., 2013) including those developed by the IEA (International Energy Agency, 2013) and the Organisation for Economic Co-operation and Development (OECD) (OECD, 2006b, 2007). However these infrastructure forecasts, typically by region or country, do not specify the portion of the forecasted infrastructure in urban areas and other settlements. One study finds that both ageing and urbanization can have substantial impacts on emissions in certain world regions such as the United States, the EU, China, and India. Globally, a 16–29% reduction in the emissions by 2050 (1.4–2.5 GtC/yr) could be achieved through slowing population growth (O'Neill et al., 2010).

12.3 Urban Systems: Activities, Resources, and Performance

How does urbanization influence global or regional CO_2 emissions? This section discusses drivers of urban GHG emissions, how they affect different sectors, and their interaction and interdependence. The magnitude of their impact on urban GHG emissions is also discussed qualitatively and quantitatively to provide context for a more detailed assessment of urban form and infrastructure (12.4) and spatial planning (12.5).

12.3.1 Overview of drivers of urban GHG emissions

Urban areas and nations share some common drivers of GHG emissions. Other drivers of urban GHG emissions are distinct from national drivers and are locally specific. The previous section discussed important accounting issues that affect the estimation of urban-scale GHG emissions. (For a more comprehensive review, see Kennedy et al., 2009; ICLEI and WRI, 2012; Ramaswami et al., 2012b; Steinberger and Weisz, 2013). Another characteristic of urban areas is that their physical form and structure in terms of land-use mix and patterns, density, and spatial configuration of infrastructure can strongly influence GHG emissions (see discussion below and in 12.4). The basic constituent elements of cities such as streets, public spaces, buildings, and their design, placement, and function reflect their socio-political, economic, and technological histories (Kostof, 1991; Morris, 1994; Kostof and Tobias, 1999). Hence, cities often portray features of 'path dependency' (Arthur, 1989), a historical contingency that is compounded by the extent of pre-existing policies and market failures that have lasting impacts on emissions (see Section 12.6 below).

The following sections group and discuss urban GHG emission drivers into four clusters that reflect both the specificity of urban scale emissions as well as their commonality with national-scale drivers of GHG emissions addressed in the other chapters of this assessment:

- Economic geography and income
- Socio-demographic factors
- Technology
- Infrastructure and urban form

Economic geography refers to the function of a human settlement within the global hierarchy of places and the international division of labour, as well as the resulting trade flows of raw materials, energy, manufactured goods, and services. Income refers to the scale of economic activity, often expressed through measures of Gross Regional Product (GRP) (i.e., the GDP equivalent at the scale of human settlements), calculated either as an urban (or settlement) total, or normalized on a per capita basis.

Socio-demographic drivers of urban GHG emissions include population structure and dynamics (e.g., population size, age distribution, and household characteristics) (O'Neill et al., 2010) as well as cultural norms (e.g., consumption and lifestyle choices) and distributional and equity factors (e.g., access or lack thereof to basic urban infrastructure). Unequal access to housing and electricity is a significant social problem in many rapidly growing cities of the Global South (Grubler and Schulz,

2013) and shapes patterns of urban development. Here, ‘technology’ refers to macro-level drivers such as the technology of manufacturing and commercial activities. ‘Infrastructure’ and ‘urban form’ refer to the patterns and spatial arrangements of land use, transportation systems, and urban design elements (Lynch, 1981; Handy, 1996) and are discussed in greater detail in Section 12.4.

12.3.1.1 Emission drivers decomposition via IPAT

Explaining GHG emission growth trends via decomposition analysis is a widely used technique in the scientific literature and within IPCC assessments ever since Kaya (1990). The so-called IPAT identity (for a review, see Chertow, 2000) is a multiplicative identity in which Impacts (e.g., emissions) are described as being the product of Population *x* Affluence *x* Technology. First derivatives (growth rates) of the components of this identity become additive, thus allowing a first analysis on the relative weight of different drivers. The IPAT identity is a growth accounting framework and does not lend itself to explaining differences between urban settlements in terms of absolute GHG emission levels and their driving forces (see discussion below).

There is great interest in understanding the drivers of China’s urban GHG emissions, which has resulted in a large literature on the decomposition of GHG emissions for Chinese megacities. With approximately 10 tonnes of CO_2 per urban capita—three times the national average—China approaches and in some cases, surpasses levels for Annex-I countries and cities (Dhakal 2009). Studies have used national emission inventory methods following the IPCC/OECD guidelines (Dhakal, 2009; Chong et al., 2012) or input-output techniques (Wang et al., 2013) and thus have used both production and consumption accounting perspectives. Studies have also gone beyond the simple IPAT accounting framework, such as using index decomposition (Donglan et al., 2010). Together, these studies show considerable variation in per capita GHG emissions across Chinese cities (see, for example, Figure 12.9). Although the relative contribution of different drivers of emissions varies across cities and time periods, one study of several Chinese cities found that income is the most important driver of increases in urban carbon emissions, far surpassing population growth, with improvements in energy efficiency serving as a critical counterbalancing factor to income growth (Dhakal 2009). The importance of economic growth as a driver of urban CO_2 emissions in China has been consistently corroborated in other studies, including those that examine relatively smaller cities and with the use of alternative types of data and methods (Li et al., 2010; Liu et al., 2012; e.g. Chong et al., 2012; Jiang and Lin, 2012).

However, the evidence on whether the gains in efficiency can counterbalance the scale of infrastructure construction and income growth in China is less conclusive. Several studies implemented at different spatial scales have found that the scale of urbanization and associated consumption growth in China have outpaced gains from improvements in efficiency (Peters et al., 2007; Feng et al., 2012; Güneralp and Seto, 2012). Other studies have found that improvements in efficiency offset the increase in consumption (Liu et al., 2007; Zhang et al., 2009; Minx et al., 2011).

The literature on drivers of urban GHG emissions in other non-Annex I countries is more sparse, often focusing on emission drivers at the sectoral level such as transport (Mraihi et al., 2013) or household energy use (Ekholm et al., 2010). In these sectoral studies, income and other factors (that are highly correlated with income) such as vehicle ownership and household discount rates, are also shown as important determining variables.

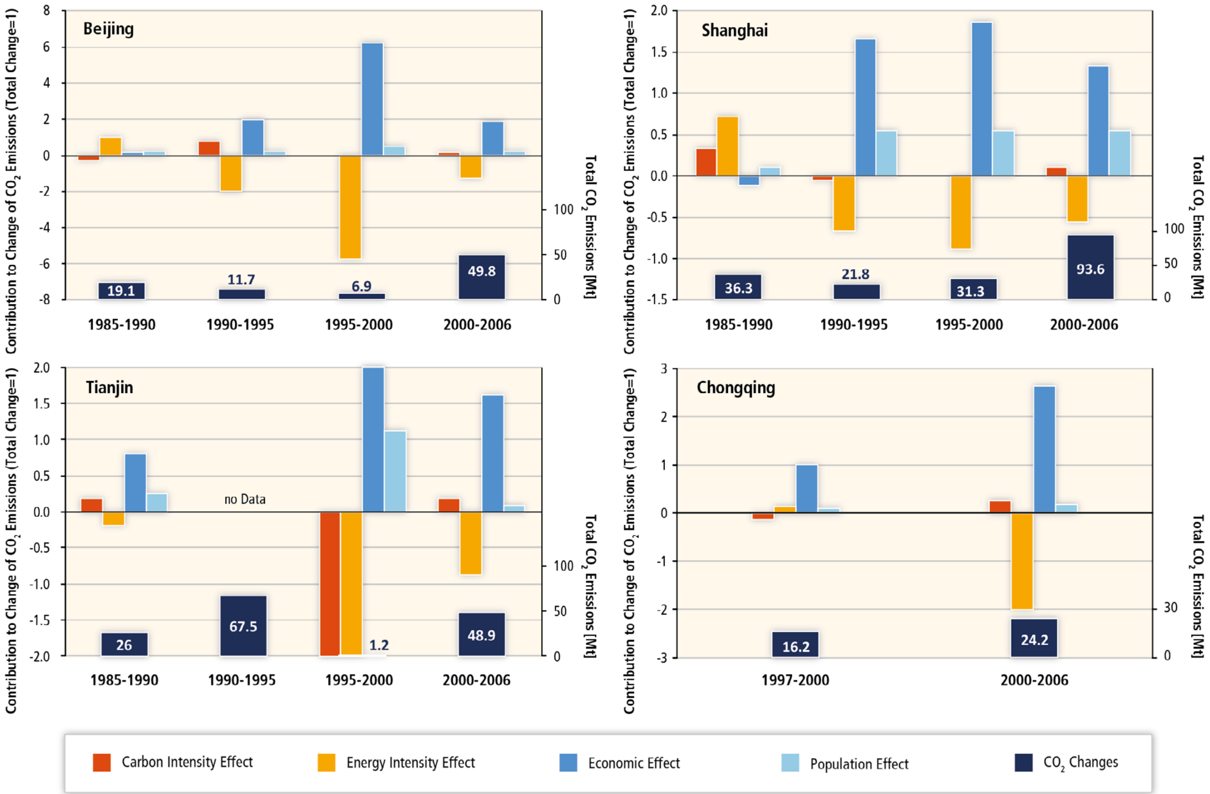


Figure 12.9. Decomposition of urban-scale CO_2 emissions (absolute difference over time period specified (dark blue) and renormalized to index 1 (other colours)) for four Chinese cities 1985 to 2006 (Dhakal, 2009). Note the ‘economic effect’ in the graph corresponds to an income effect as discussed in the text. For comparison, per capita CO_2 emissions for these four cities range between 11.7 (Shanghai), 11.1 (Tianjin), 10.1 (Beijing), and 3.7 (Chongqing) tCO_{2}/cap (Hoornweg et al., 2011).

Decomposition analyses are available for cities in the United States (Glaeser and Kahn, 2010), the UK (Minx et al., 2013), Japan (Makido et al., 2012), and Australia (Wiedenhofer et al., 2013). These studies show that income is an important driver of urban GHG emissions. Studies using more disaggregated emission accounts complement these findings by also identifying other significant influencing factors including automobile dependence, household size, and education (Minx et al., 2013) or additional variables such as climate represented by heating- or cooling-degree days (Wiedenhofer et al., 2013). The latter two studies are of particular interest as they provide an in-depth analysis of the determining variables of urban GHG emissions using both production and consumption-based accounting approaches. In both accounting approaches, income emerges as an important determinant of urban GHG emissions.

12.3.1.2 Interdependence between drivers

The drivers outlined above vary in their ability to be influenced by local decision making. It is difficult to isolate the individual impact of any of these factors on urban energy use and GHG emissions since they are linked and often interact across different spatial and temporal scales. The interaction among the factors and the relative importance of each will vary from place to place. Moreover, many of these factors change over time and exhibit path dependence.

A legitimate concern with the IPAT decomposition approach is that the analysis assumes variable independence, thus ignoring variable interdependence and co-variance. For instance, a study of 225 cities suggests a robust negative correlation between per capita income levels and energy intensity (Grubler et al., 2012) that holds for both high-income as well as low-income cities. Income growth has the potential to drive investment in technology, changing investment in newer and more efficient technologies, as higher income segments have lower discount rates or higher tolerance to longer payback times (Hausman, 1979).

12.3.1.3 Human settlements, linkages to sectors, and policies

The major drivers discussed above affect urban GHG emissions through their influence on energy demand in buildings, transport, industry, and services. These can be mitigated through demand-side management options. As such, human settlements cut across the assessment of mitigation options in sector-specific chapters of this Assessment (see Table 12.4). The drivers also affect the demand for urban energy, water, and waste infrastructure systems, whose GHG emissions can be mitigated via technological improvements within each individual infrastructure system (e.g., methane recovery from municipal wastewater treatment plants and landfills) as well as through improved system integration (e.g., using urban waste as an energy source). Given the interdependence between drivers and across driver groups discussed above, independent sectoral assessments have limitations and risk omitting important mitigation potentials that arise from systems integration.

Table 12.4. Examples of policies across sectors and mitigation options at the scale of human settlements.

	ENERGY SYSTEMS (Chapter 7)	**TRANSPORT** (Chapter 8)	**BUILDINGS** (Chapter 9)	**INDUSTRY** (Chapter 10)	**AFOLU** (Chapter 11)
Carbon Sinks / Sequestration					Tradable Credits, EQ Policies
Energy Efficiency	Taxes, Credits/ Permits	Subsidies for Fuel Efficiency, Standards, Targets	Taxes, Preferential Lending, Codes, Standards	Taxes, Standards, Emissions Trading, Target-setting	
Fuel / Energy Switching / Renewables	Taxes, EQ Policies, Ren Energy Portfolio Stds, Energy Security Policies	Taxes, Biofuel Incentives, Standards			Taxes, Targets, Subsidies
High-Performance / Passive Design		Bike sharing, Urban Planning	Codes, Standards, Integrated Planning, Certification		
Improved Planning / Management	Demand Response Measures	Integrated Planning	Commissioning, Audits, Education		Land Planning, Protected Areas
Materials Efficiency			Codes, Standards, Taxes, LCA, Certification	Standards	Taxes
New/ Improved Technology	R&D Policies, Low Carbon Tech Targets	Subsidies for Fuel Efficiency, Bike Sharing, Real-time Information	Real-time Information		Bioenergy Targets
Recycling / Reducing Waste				Taxes, Target-setting, Education	Education
Reduced Demand / Behavior Change		Tolls, Congestion Pricing		Taxes, Subsidies, Education	Education, Standards
Urban Form / Density		Smart Growth, Urban Planning, Growth Management	Certification, Urban Planning		

On one hand, governance and institutions for addressing mitigation options at the urban scale are more dispersed (see 12.6) and face a legacy of inadequately addressing a range of market failures (see Box 12.3). On the other hand, the urban scale also provides unique opportunities for policy integration between urban form and density, infrastructure planning, and demand management options. These are key, especially in the domain of urban transport systems. Lastly, governance and institutional capacity are scale and income dependent, i.e., tend to be weaker in smaller scale cities and in low income/revenue settings. In so far as the bulk of urban growth momentum is expected to unfold in small- to medium-size cities in non-Annex I countries (see Section 12.2), mitigation of GHG emissions at the scale of human settlements faces a new type of 'governance paradox' (Grubler et al., 2012): the largest opportunities for GHG emission reduction (or avoidance of unfettered emission growth) might be precisely in urban areas where governance and institutional capacities to address them are weakest (Bräutigam and Knack, 2004; Rodrik et al., 2004).

12.3.2 Weighing of Drivers

This section assesses the relative importance of the GHG drivers in different urban contexts such as size, scale, and age, and examines the differences between cities in developed and developing countries.

12.3.2.1 Qualitative weighting

In the previous discussion of the respective role of different emission drivers, the emphasis was placed on the role of drivers in terms of emission growth. That perspective is complemented in this section by a consideration of the absolute level of emissions, and the issue of urban size/scale. This section also differentiates the role of emission drivers between mature versus growing human settlements.

Importance of size and scaling

Given the significance of human settlements for global resource use, an improved understanding of their size distribution and likely growth dynamics is crucial. For many physical, biological, social, and technological systems, robust quantitative regularities like stable patterns of rank distributions have been observed. Examples of such power law-scaling patterns include phenomena like the frequency of vocabulary in languages, the hierarchy of urban population sizes across the world (Zipf, 1949; Berry and Garrison, 1958; Krugman, 1996) or the allometric scaling patterns in biology, such as Kleiber's Law, which observes the astonishing constancy in the relation between body mass and metabolic rates: for living organisms across many orders of magnitude in size that metabolic rate scales to the ¾ power of the body mass (Kleiber, 1961). There is a vigorous debate in many fields, including Geography (Batty, 2005, 2008), Ecology (Levin, 1992; West et al., 1999; Brown et al., 2004), Architecture (Weinstock, 2011), and Physics (Carvalho and Penn, 2004) about the extent to which underlying hierarchical networks of metabolic systems or transportation networks are the ultimate causes of the size, shape and rank-distribution of entities, be they organisms or urban systems (Decker et al., 2000, 2007).

With the scale of urbanization trends currently underway, whether the relationship between city size and GHG emissions is linear (i.e., one to one, or proportional increase), super-linear (i.e., increasing returns to scale) or sub-linear (i.e., economies of scale such as efficiency gains through shared infrastructure) will be critical for understanding future urban GHG emissions. Super-linear scaling has been observed for many urban phenomena: as a city's population increases, there is a greater than one to one increase in productivity, wages, and innovation as well as crime (Bettencourt et al., 2007, 2010). If cities exhibit sub-linear scaling with respective to energy and GHG emissions, it suggests that larger cities are more efficient than smaller ones. While there are many studies of urban scaling, few studies explicitly examine city size and GHG emissions or energy use, and the limited empirical evidence on the scaling relationship is inconclusive. A study of 930 urban areas in the United States—nearly all the urban settlements—shows a barely sub-linear relationship (coefficient=0.93) between urban population size and GHG emissions (Fragkias et al., 2013).

In a study of 225 cities across both Annex I and non-Annex I countries, Grubler and Schulz (2013) find non-uniform scaling for urban final energy use, with a distribution characterized by threshold effects across an overall convex distribution (Figure 12.10). In terms of final energy use, which is an important determinant of urban GHG emissions, increasing the urban scale in terms of energy use has different implications as a function of three different urban energy scale classes. Small cities with low levels of final energy use—below 30 PJ—present the steepest growth in energy use with respect to increasing city size: a doubling of rank position tends to increase the urban energy use by a factor of 6.1. For medium-sized cities with moderate energy use (between 30 and 500 PJ final energy use per city), a doubling of city rank corresponds to an increase in energy consumption only by a factor of 1.6. For the largest urban energy users in the dataset, cities with greater than 500 PJ of final energy use per year, a doubling of urban rank is associated with an increase in urban energy use by a factor of only 0.5. This indicates considerable positive agglomeration economies of bigger cities with respect to energy use. Only four urban agglomerations of the entire sample of 225 have an annual final energy use significantly greater than one EJ: Shanghai (2 EJ), Moscow (1.6 EJ), Los Angeles (1.5 EJ), and Beijing (1.2 EJ). With urban growth anticipated to be the most rapid in the smaller cities of fewer than 500,000 inhabitants (UN DESA, 2010), the patterns observed by (Grubler and Schulz, 2013) suggest very high elasticities of energy demand growth with respect to future increases in urban population.

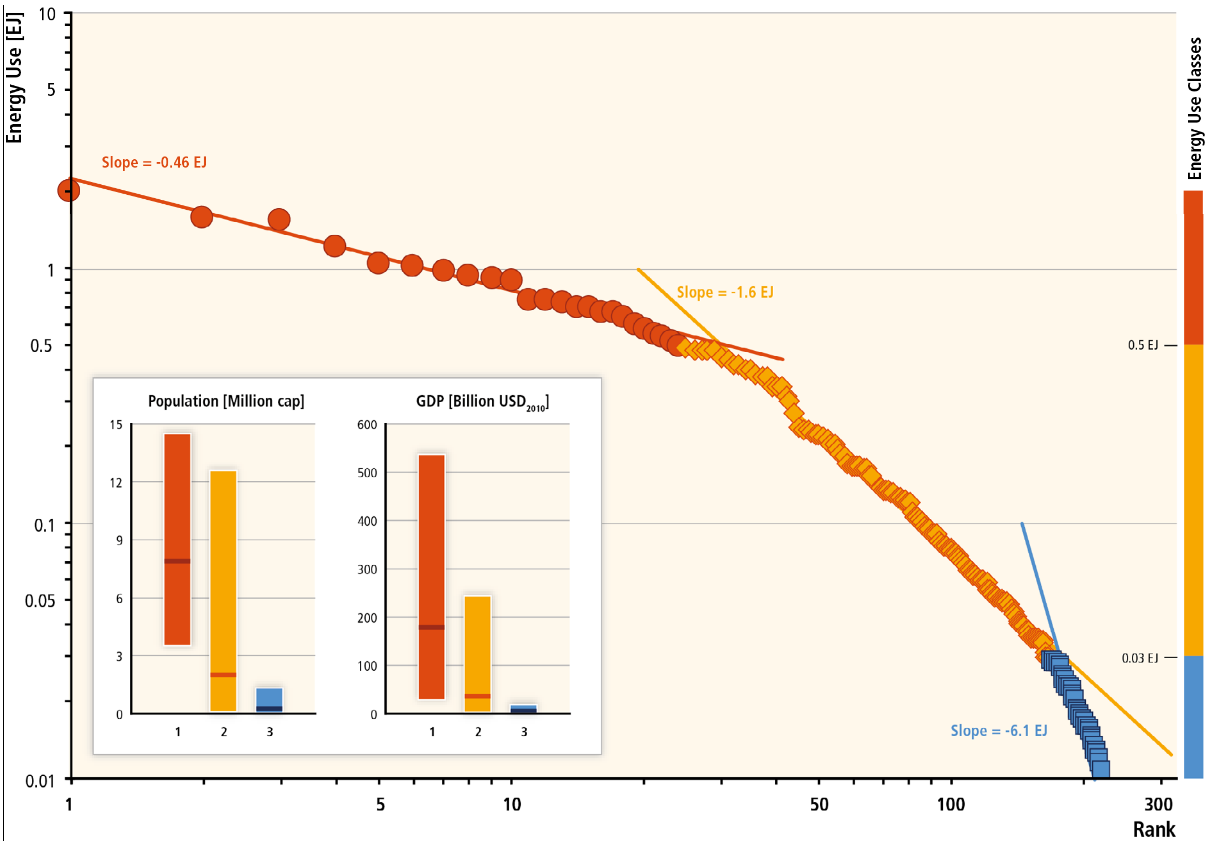


Figure 12.10. Rank size distribution of 225 cities in terms of their final energy use (in EJ) regrouped into 3 subsamples (>0.5EJ, 0.03-0.5EJ, <0.03EJ) and corresponding sample statistics. The rank of a city is its position in the list of all cities sorted by size, measured in terms of final energy use. Note the different elasticities of energy use with respect to changes in urban size rank. The factors (slopes) shown in the figure detail the increase of energy use when doubling the rank for the respective groups. Source: (Grubler and Schulz, 2013).

Mature versus growing cities

The relative impacts of the four drivers on emissions differ depending upon whether urban areas are established and mature versus growing and developing.

Economic geography and income have high impact for both mature and growing cities. Mature cities in developed countries often have high income, high consumption, and are net consumers of goods and services, with a large share of imports. These cities have high emissions, depending upon the energy supply mix. Many imported goods are produced in growing cities in developing countries. The resulting differentiation within the international division of labour and corresponding trade flows can be categorized into three types of cities: Net Producers, Trade Balanced, and Net Consumers (Chavez and Ramaswami, 2013). As a result, differences in reported urban GHG emissions are pronounced for Net Producer and Net Consumer cities, illustrating the critical importance of taking economic geography and international trade into account when considering urban GHG emission inventory frameworks. The degree to which economic growth drives GHG emissions includes the type of economic specialization of urban activities and the energy supply mix (Brownsword et al., 2005; Kennedy et al., 2012). Cities with energy intensive industries are likely to contribute higher total and per capita GHG emissions than those whose economic base is in the service sector (Dhakal, 2009, 2010). Specialization in energy-intensive sectors creates a strong correlation between economic growth and GHG emissions growth. This relationship is further strengthened if the energy supply mix is carbon intensive (Parikh and Shukla, 1995; Sugar et al., 2012).

Higher **urban incomes** are correlated with higher consumption of energy and GHG emissions (Kahn, 2009; Satterthwaite, 2009; Kennedy et al., 2009; Weisz and Steinberger, 2010; Zheng et al., 2010; Hoornweg et al., 2011; Marcotullio et al., 2012). At the household level, studies in a variety of different countries (Netherland, India, Brazil, Denmark, Japan, and Australia) have also noted positive correlations between income and energy use (Vringer and Blok, 1995; Cohen et al., 2005; Lenzen et al., 2006; Pachauri and Jiang, 2008; Sahakian and Steinberger, 2011). As such, income exerts a *high* influence on GHG emissions. The Global Energy Assessment concluded that cities in non-Annex I countries generally have much higher levels of energy use compared to the national average, in contrast to cities in Annex I countries, which generally have lower energy use per capita than national averages (see Figure 12.6 and Grubler et al., 2012). One reason for this inverse pattern is due to the significantly higher urban to rural income gradient in cities in non-Annex I countries compared to Annex I countries. That is, per capita incomes in non-Annex I cities tend to be several fold higher than rural per capita incomes, thus leading to much higher energy use and resulting emissions.

Socio-demographic drivers are of *medium* importance in rapidly growing cities, further mediated as growth rates decline, incomes increase and lifestyle choices change. Social demographic drivers are of *relatively small* importance in mature cities, where growth is slow and populations are ageing. Household size, defined as the number of persons in a household, has been steadily declining over the last fifty years. Worldwide, average household size declined from 3.6 to 2.7 between 1950 to 1990, and this trend is occurring in both developed and developing countries although at different rates (MacKellar et al., 1995; Bongaarts, 2001). Smaller household size is correlated with higher per capita emissions, whereas larger household size can take advantage of economies of scale. Evidence on the relationship between urban population size and per capita emissions is inconclusive. Scale effects have been shown for cities in Asia (Marcotullio et al., 2012) but little to no scaling effect for GHG emissions in the United States (Fragkias et al., 2013).

Infrastructure and urban form are of *medium to high* importance as drivers of emissions. In rapidly growing cities, infrastructure is of high importance where the largest share of infrastructure construction is occurring. In mature cities, urban form drivers are of high importance as they set in place patterns of transport and other energy use behaviour. In mature cities, infrastructure is of medium importance, as they are largely established, and thus refurbishing or repurposing of old infrastructures offers primary mitigation opportunities. The global expansion of infrastructure used to support urbanization is a key driver of emissions across multiple sectors. Due to the high capital costs, increasing returns, and network externalities related to infrastructures that provide fundamental services to cities, emissions associated with infrastructure systems are particularly prone to lock-in (Unruh and Carrillo-Hermosilla, 2006; Unruh, 2002, 2000). The committed emissions from energy and transportation infrastructures are especially high, with respective ranges of committed CO_2 of 127–336 and 63–132 Gt (Davis et al., 2010). For example, the GHG emissions from primary production alone for new infrastructure development for non-Annex I countries are projected to be 350 Gt CO_2 (Müller et al., 2013). For a detailed discussion see Sections 12.4 and 12.5.

Technology is a driver of *high* importance. Income and scale exert important influences on the mitigation potential for technologies. While lock-in may limit the rate of mitigation in mature cities, the opportunity exists in rapidly growing cities to leapfrog to new technologies. For mature cities, technology is important due to agglomeration externalities, Research and Development (R&D) and knowledge concentration, and access to capital that facilitate the development and early deployment of low-carbon technologies (Grubler et al., 2012). For rapidly growing cities, the importance of technology as a driver may be low for systems with high capital requirements but high for less capital-intensive (e.g., some demand-side efficiency or distributed supply) systems. The influence of all drivers depends upon governance, institutions, and finance (Section 12.6).

12.3.2.2 Relative weighting of drivers for sectoral mitigation options

Drivers affect GHG emissions via influence on energy demand (including demand management) in buildings (households and services), transport, and industry, as well as on energy supply, water, and waste systems. Over time, structural transitions change both the shares of emissions by sectors—with industrial, then services and transport shares of final energy increasing with development (Schäfer, 2005; Hofman, 2007)—as well as the relative importance of drivers. Economic geography has a large influence on emissions from the industry and service sectors (Ramaswami, 2013) plus international transport (bunkers fuels). These influences are particularly pronounced in urban agglomerations with very porous economies. For example Schulz (2010) analyzed Singapore and found that GHG emission embodied in the imports and exports of the city are five to six times larger than the emissions from the direct primary energy use of the city's population. Similarly, Grubler et al. (2012) examined New York and London, which are global transportation hubs for international air travel and maritime commerce. As a result, international aviation and maritime fuels (bunker fuels) make up about one-third of the total direct energy use of these cities, even if associated emissions are often excluded in inventories, following a practice also used in national GHG emission inventories (Macknick, 2011).

Income has a large influence on direct emissions due to energy use in buildings by influencing the floor area of residential dwellings, the amount of commercial floor space and services purchased, and buildings' energy intensities (see Table 9.2), and also on transport, including increasing vehicle ownership, activity, energy intensity and infrastructure (see Chapter 8.2). Income also has large indirect effects on emissions, for example influencing the number of products purchased (e.g., increasing sales of electronics) (see Chapter 10.2) and their energy intensity (e.g., consumables like food) (see Chapter 11.4), perhaps produced by the industrial and services sectors somewhere else, and transported to the consumers (increasing freight transport activity).

Social demographic drivers have a large effect on emissions, particularly in buildings (e.g., number of households, persons per household (see Chapter 9.2.2)) and transport sectors (see Chapter 8.2.1). Infrastructure and urban form have a large impact on transport (Chapter 8.4) and medium impact on energy systems (grid layout and economics) (see Chapter 7.6). Technology has a large impact in all sectors. Income interacts with technology, increasing both innovative (e.g., R&D) and adoptive capacity (purchases and replacement rate of products, which in turn can increase energy efficiency). In demand sectors, mitigation from efficiency may be mediated by behaviours impacting consumption (e.g., more efficient yet larger televisions or refrigerators, or more efficient but larger or more powerful vehicles). See the sectoral Chapters 7–11 for further discussion of these issues.

12.3.2.3 Quantitative modelling to determine driver weights

An inherent difficulty in any assessment of emission drivers at the urban scale is that both mitigation options as well as policy levers are constrained by the legacy of past decisions as reflected in existing urban spatial structures and infrastructures, the built environment, and economic structures. Modelling studies that simulate alternative development strategies, even the entire evolution of a human settlement, or that explore the effects of policy integration across sectors can shed additional light on the relative weight of drivers as less constrained or entirely unconstrained by the existing status quo or by more limited sectoral assessment perspectives.

For instance, large-scale urban simulation models have been used to study the joint effects of policy integration such as pursuing smart-growth planning that restricts urban sprawl with market-based pricing mechanisms. One study of metropolitan regions in OECD countries concludes that policies such as those that encourage higher urban densities and road tolls such as congestion charges have lower stabilization costs than economy-wide approaches such as a carbon tax (Crassous et al., 2006; OECD, 2010a) . Models suggest that adding substantially upgraded urban services to the mix of bundled strategies yields even greater benefits. A meta-analysis of 14 urban simulations of scenarios with varying degrees of urban containment, road pricing, and transit services upgrades forecasted median transportation demand volumes (VKT, vehicle-kilometer-travelled) reductions of 3.9% within 10 years, rising to 15.8% declines over 40 years (Rodier, 2009). Estimates from a review of published studies of U.S. cities forecasted a 5% to 12% VKT reduction from doubling residential densities and as high as 25% reductions when combined with other strategies, including road pricing (National Research Council, 2009a). GHG emissions were estimated to decline 11% from the most aggressive combination of densification and market-based pricing. The combination of introducing VKT charges, upgrading transit, and more compact development from simulation studies in Helsinki, Dortmund, Edinburgh, and Sacramento yielded simulation-model estimates of 14.5% reductions in VKT within 10 years and 24.1% declines over 40 years (Rodier, 2009).

A more holistic modelling strategy with a much larger system boundary was followed with the Sincity model, a combined engineering-type systems-optimization model that integrates agent-based and spatially explicit modelling of urban form and density with transport and energy infrastructure planning to simulate the entire evolution of a 'synthetic' city (Keirstead and Shah, 2013; Steinberger and Weisz, 2013) or of large scale new urban developments (Hao et al., 2011). Using an illustrative European city of 20,000 inhabitants and with a service dominated economy (i.e., holding the economic geography and income variables constant), alternative urban designs were explored to separate out the various effects of different policy measures in determining urban energy use. The results suggest that compared to a baseline (sprawl city with current practice technologies), improvements by a factor of two each were possible by either a combination of energy efficiency measures for the urban building stock and the vehicle fleet, versus modifying urban form and density. Conversely energy systems optimization through cogeneration and distributed energy systems were found to yield improvements of between 15–30% (Keirstead and Shah, 2013; Steinberger and Weisz, 2013). The largest improvements of a factor of three were found through an integration of policy measures across all domains.

12.3.2.4 Conclusions on drivers of GHG emissions at the urban scale

Perhaps the most significant conclusion emerging from Section 12.2 and above discussion of urban GHG emission drivers is the realization that the traditional distinction between Annex I and non-Annex I becomes increasingly blurred at the urban scale. There is an increasing number of cities, particularly in the rapidly growing economies of Asia, where per capita resource use, energy consumption, and associated GHG emissions are not different from the ones in developed economies. A second important conclusion is that economic geography and income by themselves are often such important drivers of urban GHG emissions that they dwarf the effects of technology choices or of place-based policy variables of urban form and infrastructures. However, the latter policy options are those for which urban-scale decision making can make the *largest* impact on GHG emissions.

A more detailed discussion on the different leverage effects of urban scale policy options using the example of urban energy use is provided in the Global Energy Assessment, Chapter 18 (Grubler et al., 2012), which can be combined with above assessment on the relative weight of emission drivers to derive a categorization of urban policy intervention levels as a function of potential impacts on emissions as well as the degree to which policy interventions can be implemented by urban-scale decision making processes by local governments, firms, and individuals (Figure 12.11).

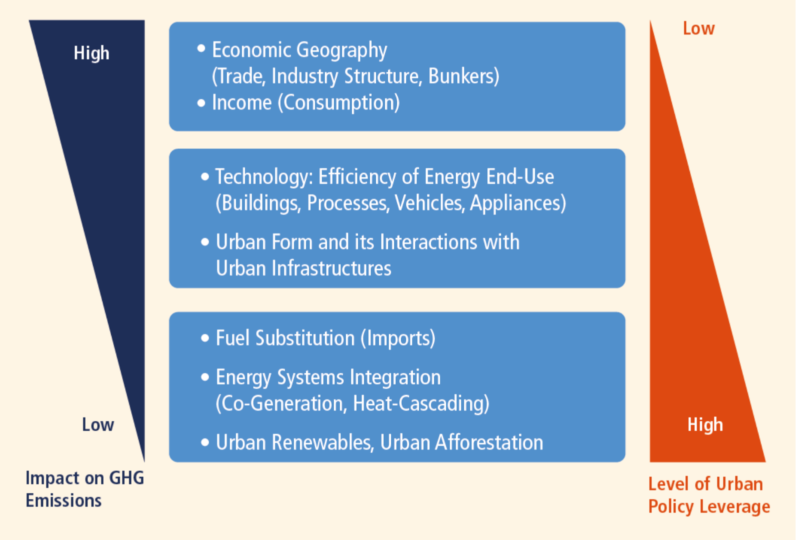


Figure 12.11. Stylized hierarchy of drivers of urban GHG emissions and policy leverages by urban scale decision making. Cities have little control over some of the most important drivers of GHG emissions and have large control over comparatively smaller drivers of emissions. Source: synthesized from (Jaccard et al., 1997; Grubler et al., 2012) and this assessment.

The categorization in Figure 12.11 is necessarily stylized. It will vary across local contexts, but it helps to disentangle the impacts of macro- from micro-drivers. For instance, urban GHG emission levels will be strongly influenced by differences in urban function, such as the role of a city as a manufacturing centre for international markets, versus a city providing service functions to its regional or national hinterlands. Conversely, the emissions impact from smaller-scale decisions such as increasing local and urban-scale renewable energy flows—which has been assessed to be very limited, particularly for larger and more dense cities (Grubler et al., 2012)—is much smaller. The largest leverage on urban GHG emissions from urban scale decision making thus is at the 'meso' scale level of the energy/emissions and urban policy hierarchy: improving the efficiency of equipment used in a city, improving and integrating urban infrastructure, and shaping urban form towards low carbon pathways. Pursuing multiple strategies simultaneously at this scale may be most effective at reducing the urban-related emissions. This conclusion echoes concepts such as integrated community-energy-management strategies (Jaccard et al., 1997).

12.3.3 Motivation for assessment of spatial planning, infrastructure, and urban form drivers

Urban form and infrastructure significantly affect direct (operational) and indirect (embodied) GHG emissions, and are strongly linked to the throughput of materials and energy in a city, the waste that it generates, and system efficiencies of a city. Mitigation options vary by city type and development levels. The options available for rapidly developing cities include shaping their urbanization and infrastructure development trajectories. For mature, built-up cities, mitigation options lie in urban regeneration (compact, mixed-use development that shortens journeys, promotes transit/walking/cycling, adaptive reuse of buildings) and rehabilitation/conversion to energy-efficient building designs. Urban form and infrastructure are discussed in detail in Section 12.4. A combination of integrated sustainable infrastructure (Section 12.4), spatial planning (Section 12.5), and market-based and regulatory instruments (Section 12.6) can increase efficiencies and reduce GHG emissions in already built-up cities and direct urban and infrastructure development to reduce the growth of GHG emissions in rapidly expanding cities in developing countries.

12.4 Urban Form and Infrastructure

Urban form and structure are the patterns and spatial arrangements of land use, transportation systems, and urban design elements, including the physical urban extent, layout of streets and buildings, as well as the internal configuration of settlements (Lynch, 1981; Handy, 1996). Infrastructure comprises services and built-up structures that support the functions and operations of cities, including transport infrastructure, water supply systems, sanitation and wastewater management, solid waste management, drainage and flood protection, telecommunications, and power generation and distribution. There is a strong connection between infrastructure and urban form (Kelly, 1993; Guy and Marvin, 1996), but the causal order is not fully resolved (Handy, 2005). Transport, energy, and water infrastructure are powerful instruments in shaping where urban development occurs and in what forms (Hall, 1993; Moss, 2003; Muller, 2004). The absence of basic infrastructure often—but not always—inhibits urban development.

This section assesses the literature on urban form and infrastructure drivers of GHG emissions, details what data exist, the ranges, effects on emissions, and their interplay with the drivers discussed in Section 12.3. Based on this assessment, conclusions are drawn on the diversity of favourable urban forms and infrastructure highlighting caveats and conflicting goals. This literature is dominated by case studies of cities in developed countries. The literature on conditions in developing country cities, especially for large parts of Africa, is particularly limited. This assessment reflects this limitation in the literature.

12.4.1 Infrastructure

Infrastructure affects GHG emissions primarily during three phases in its lifecycle: 1) construction, 2) use/operation, and 3) end-of-life. The production of infrastructure materials such as concrete and metals is energy and carbon intensive (Cole, 1998; Horvath, 2004). For example, the manufacturing of steel and cement, two of the most common infrastructure materials, contributed to nearly 9% and 7%, respectively, of global carbon emissions in 2006 (Allwood et al., 2010). Globally, the carbon emissions embodied in built-up infrastructure as of 2008 was estimated to be 122 (−20/+15) Gt CO_2 (Müller et al., 2013). Much of the research on the mitigation potential of infrastructure focuses on the use/operation phase and increasing the efficiency of the technology. Estimating emissions from urban infrastructure such as electricity grids and transportation networks is challenging because they often extend beyond a city's administrative boundaries (Ramaswami et al., 2012b) (see Section 12.2 for detailed discussion). Several studies show that the transboundary emissions of infrastructure can be as large as or even larger than the direct GHG emissions within city boundaries (Ramaswami et al., 2008; Kennedy et al., 2009; Hillman and Ramaswami, 2010; Chavez and Ramaswami, 2013). Thus, a full accounting of GHG emissions from urban infrastructure would need to include both primary and embodied energy of infrastructure materials, as well as energy from the use/operation phase and end-of-life, including reuse and recycling.

Rates of infrastructure construction in mature versus rapidly developing cities lead to fundamentally different impacts on GHG emissions. Infrastructure growth is hypothesized to follow an S-shaped curve starting with an early development phase, continuing with a rapid growth and expansion phase, and ending with a saturation phase (Ausubel and Herman, 1988). The build-up of infrastructure that occurs during early phases of urbanization is particularly emissions intensive. Currently, the average per capita emissions embodied in the infrastructure of industrialized countries is 53 (±6) t CO_2 (see Figure 12.12) which is more than five times larger than that in developing countries (10 (±1) t CO_2) (Müller et al., 2013). While there have been energy efficiency improvements in the industrial sector, especially steel and cement production, the scale and pace of urbanization can outstrip efficiency gains and lead to continued growth in emissions (Levine and Aden, 2008; Güneralp and Seto, 2012). China accounts for roughly 37% of the global emissions commitments in part due to its large-scale urbanization– the United States adds 15%; Europe 15%, and Japan 4%, together representing 71% of total global emissions commitments by 2060 (Davis et al., 2010).

Emissions related to infrastructure growth are therefore tied to existing urban energy systems, investment decisions, and regulatory policies that shape the process of urban growth. The effects of these decisions are difficult to reverse: high fixed costs, increasing returns, and network externalities make emissions intensive infrastructure systems particularly prone to lock-in (Unruh and Carrillo-Hermosilla, 2006; Unruh, 2002, 2000). Furthermore, the long lifespan of infrastructure affects the turnover rate of the capital stock, which can limit the speed at which emissions in the use/operation phase can be reduced (Jaccard and Rivers, 2007).

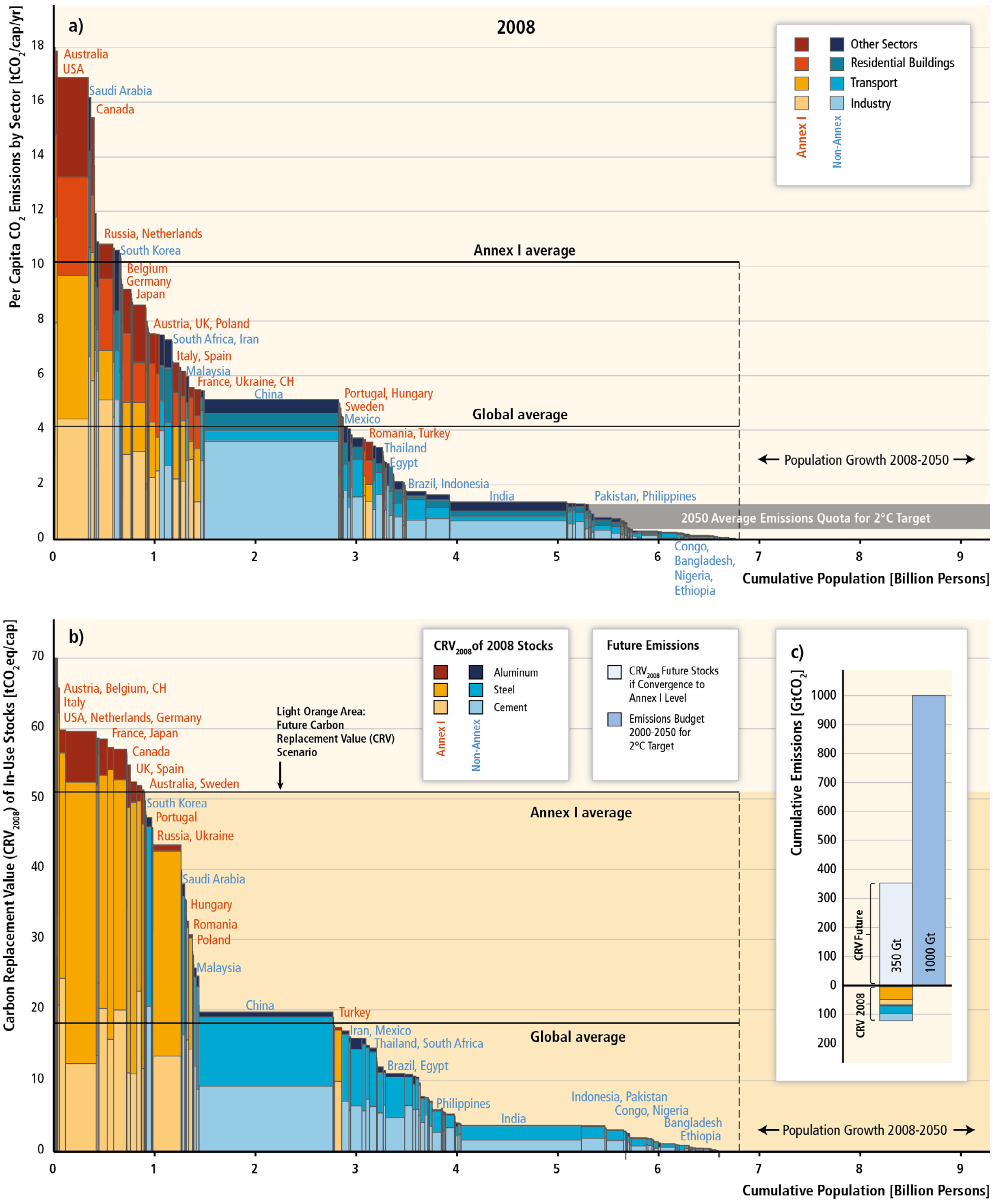


Figure 12.12. (a) Total fuel-related per-capita CO_2 emissions in 2008 by country (red/orange/yellow and blue bars) compared to the global per-capita emission level in 2050 to reach the 2 °C target with a 50−75% probability; (b) Carbon Replacement Value (CRV_{2008}) per capita of existing stocks by country (red/yellow and blue) and as yet unbuilt stocks if developing countries converge on the current average Annex I level (light orange area); (c) comparison with emission budget for the period 2000−2050 to reach the 2 °C target with a 75% probability. Of this emission budget (1000 Gt CO_2), approximately 420 $GtCO_2$ was already emitted during the period from 2000 to 2011.Source: (Müller et al., 2013).

The build-up of infrastructure in developing countries as part of the massive urbanization currently underway will result in significant future emissions. Under one scenario, if the global population increases to 9.3 billion by 2050 and developing countries expand their built environment and infrastructure to the current global average levels using available technology today, the production of infrastructure materials alone would generate approximately 470 Gt of CO_2 emissions (see Figure 12.12). This is in addition to the "committed emissions" from existing energy and transportation infrastructure, estimated to be in the range of 282 to 701 Gt of CO_2 between 2010 and 2060 (Davis et al., 2010). Under scenarios of continued expansion of infrastructure, cumulative emissions would be between 3000 to 7400 Gt of CO_2 from 2010 through the end of this century, which would lead to atmospheric concentrations greater than 600 ppm (Davis et al., 2010).

The links between infrastructure and urban form are well established, especially among transportation infrastructure provision, travel demand, and VKT. In developing countries in particular, the growth of transport infrastructure and resulting urban forms are playing important roles in affecting long-run emissions trajectories (see Chapter 8). The committed emissions from existing energy and transportation infrastructure are high, with ranges of CO_2 of 127–336 and 63–132 Gt, respectively (see Figure 12.13 and Davis et al., 2010). Transport infrastructure affects travel demand and emissions in the short-run by reducing the time cost of travel, and in the long-run by shaping land-use patterns (Vickrey, 1969; Downs, 2004). Development of transport infrastructure tends to promote 'sprawl', characterized by low-density, auto-dependent, and separated land uses (Brueckner, 2000; Ewing et al., 2003). Consistent evidence of short-run effects show that the demand elasticities range between 0.1–0.2. That is, a doubling of transport infrastructure capacity increases VKT by 10–20% in the short-run (Goodwin, 1996; Hymel et al., 2010). Other studies suggest larger short-run elasticities of 0.59 (Cervero and Hansen, 2002) and a range of 0.3–0.9 (Noland and Lem, 2002). Differences in short-run elasticities reflect fundamental differences in the methodologies underlying the studies (see Chapter 15.4 on policy evaluation). In the long-run, the elasticities of VKT with respect to road capacity are likely to be in the range 0.8–1.0 as land-use patterns adjust (Hansen and Huang, 1997; Noland, 2001; Duranton and Turner, 2011). While the links between transport infrastructure, urban form, and VKT are well studied, there are few studies that extend the analysis to estimate emissions due to transport-induced increases in VKT. One exception is a study that concludes that freezing United States highway capacity at 1996 levels would reduce emissions by 43 Mt C/yr by 2012, compared to continuing construction at historical rates (Noland, 2001).

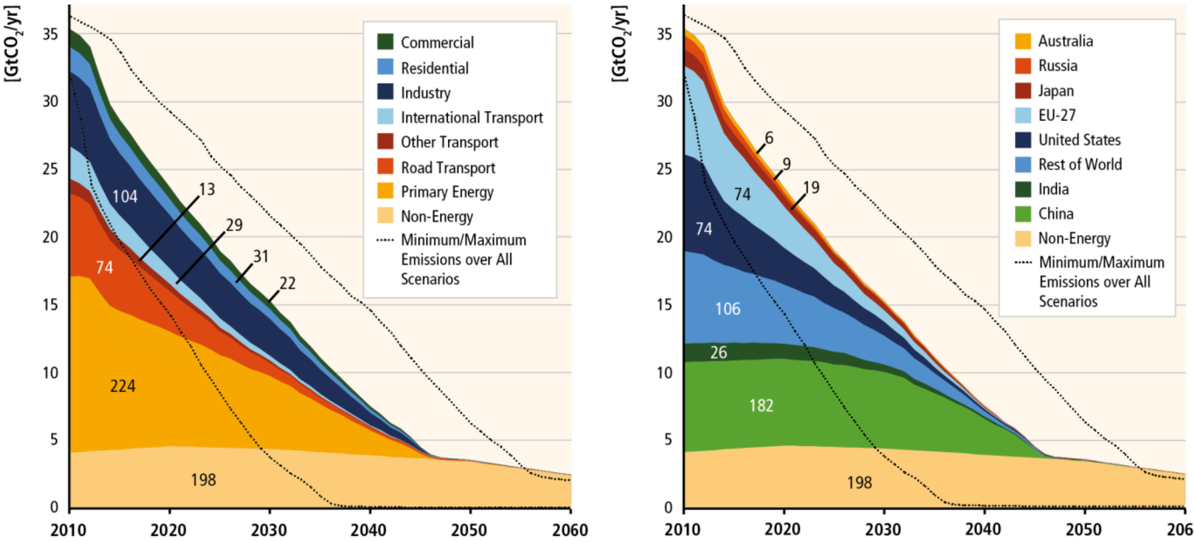


Figure 12.13. Scenario of CO_2 emissions from existing energy and transportation infrastructure by industry sector (left) and country/region (right). Source: (Davis et al., 2010).

12.4.2 Urban form

Urban form can be characterized using four key metrics: density, land use mix, connectivity, and accessibility. These dimensions are not independent from one another. Rather, they measure different aspects of urban form and structure, and each dimension impacts greenhouse gas emissions differently (Figure 12.14). The urban form drivers of GHG emissions do not work in isolation.

Impacts of changes in urban form on travel behaviour are commonly estimated using elasticities, which measure the effect of a 1% change in an urban form metric on the percent change in vehicle kilometres travelled (see Chapter 15.4 on policy evaluation). This allows for a comparison of magnitudes across different factors and metrics. A large share of the existing evidence is limited to studies of North American cities. Moreover, much of this work is focused on larger cities (for an extensive discussion of methodological considerations see National Research Council, 2009b).

12.4.2.1 Density

Urban density is the measure of an urban unit of interest (e.g., population, employment, and housing) per area unit (e.g., block, neighbourhood, city, metro area, and nation) (Figure 12.14). There are many measures of density, and three common measures are population density (i.e., population per unit area), built-up area density (i.e., buildings or urban land cover per unit area), and employment density (i.e., jobs per unit area) (for a comprehensive review on density measures see Boyko and Cooper, 2011). Urban density affects GHG emissions in two primary ways. First, separated and low densities of employment, commerce, and housing increase the average travel distances for both work and shopping trips (Frank and Pivo, 1994a; Cervero and Kockelman, 1997; Ewing and Cervero, 2001; Brownstone and Golob, 2009). These longer travel distances translate into higher VKT and emissions. Conversely, higher population densities, especially when co-located with high employment densities are strongly correlated with lower GHG emissions (Frank and Pivo, 1994b; Kenworthy and Laube, 1999; Glaeser and Kahn, 2010; Clark, 2013). In the United States, households located in relatively low density areas (0–19 households/km^2) produce twice as much GHG emissions as households located in relatively high density areas (1,900 –3,900 households/km^2) (U.S. Department of Transportation, 2009).

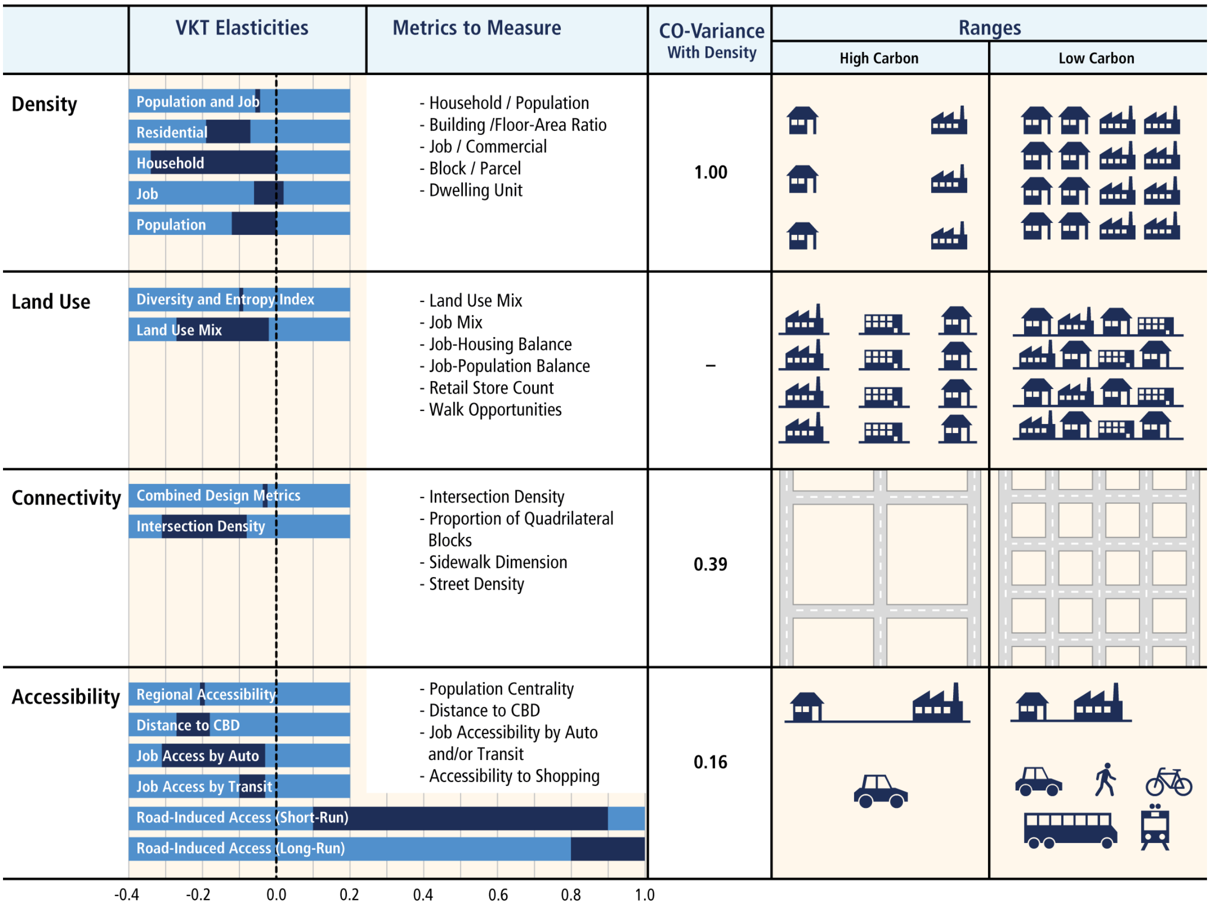


Figure 12.14. Four key aspects of urban form and structure (density, land use mix, connectivity, and accessibility), their Vehicle Kilometer Travelled (VKT) elasticities, commonly used metrics, and stylized graphics.

Sources: Numbers from Ewing and Cervero (2010), National Research Council (2009a), and Salon et al (2012) are based on the following original sources: **Density** (Schimek, 1996; Kockelman, 1997; Sun et al., 1998; Pickrell and Schimek, 1999; Ewing and Cervero, 2001; Holtzclaw et al., 2002; Bhatia, 2004; Boarnet et al., 2004; Bento et al., 2005; Zhou and Kockelman, 2008; Fang, 2008; Kuzmyak, 2009a; a; Brownstone and Golob, 2009; Ewing et al., 2009; Greenwald, 2009; Heres-Del-Valle and Niemeier, 2011); **Land Use** (Kockelman, 1997; Sun et al., 1998; Pushkar et al., 2000; Ewing and Cervero, 2001, 2010; Chapman and Frank, 2004; Frank and Engelke, 2005; Kuzmyak et al., 2006; Vance and Hedel, 2007; Brownstone and Golob, 2009; Kuzmyak, 2009b; Frank et al., 2009); **Connectivity** (Ewing and Cervero, 2001; Boarnet et al., 2004; Chapman and Frank, 2004; Frank and Engelke, 2005; Ewing et al., 2009; Greenwald, 2009; Frank et al., 2009); **Accessibility** (Goodwin, 1996; Ewing et al., 1996, 2009; Kockelman, 1997; Cervero and Kockelman, 1997; Sun et al., 1998; Pushkar et al., 2000; Ewing and Cervero, 2001, 2010; Boarnet et al., 2004; Næss, 2005; Cervero and Duncan, 2006; Christopher Zegras, 2007; Greenwald, 2009; Kuzmyak, 2009a; b; Frank et al., 2009; Zegras, 2010; Hymel et al., 2010)

Second, low densities make it difficult to switch over to less energy intensive and alternative modes of transportation such as public transportation, walking, and cycling because the transit demand is both too dispersed and too low (Bunting et al., 2002; Saelens et al., 2003; Forsyth et al., 2007). In contrast, higher population densities at places of origin (e.g., home) and destination (e.g., work, shopping) concentrate demand that is necessary for mass transit alternatives. The density thresholds required for successful transit are not absolute, and vary by type of transit (e.g., bus, light rail, metro), their frequency, and characteristics specific to each city. One of the most comprehensive studies of density and emission estimates that a doubling of residential densities in the United States can reduce VKT by 5–12% in the short run, and if coupled with mixed land use, higher employment densities, and improvements in transit, can reduce VKT as much as 25% over the long run (National Research Council, 2009a). Urban density is thus a necessary—but not a sufficient—condition for low-carbon cities.

Comparable and consistent estimates of urban densities and changes in urban densities are difficult to obtain in part because of different methodologies to calculate density. However, multiple studies using multiple lines of evidence including satellite data (Deng et al., 2008; Angel et al., 2010, 2011; Seto et al., 2011) and economic and census data (Burchfield et al., 2006) show that both population and built-up densities are declining across all regions around the world (see Section 12.2 for details). Although there is substantial variation in magnitudes and rates of density decline across income groups, city sizes, and regions, the overarching trend is a persistent decline in densities (Angel et al., 2010). The dominant trend is declining density, however there are some exceptions. Analyses of 100 large cities worldwide using a microwave scatterometer show significant vertical expansion of built-up areas in East Asian cities, notably those in China (see Figure 12.15 and Frolking et al., 2013).

A common misconception about density is that it can only be achieved through high-rise buildings configured in close proximity. However, the same level of density can be achieved through multiple land use configurations (Figure 12.16). Population density is strongly correlated with built density, but high population density does not necessarily imply high-rise buildings (Cheng, 2009; Salat, 2011).

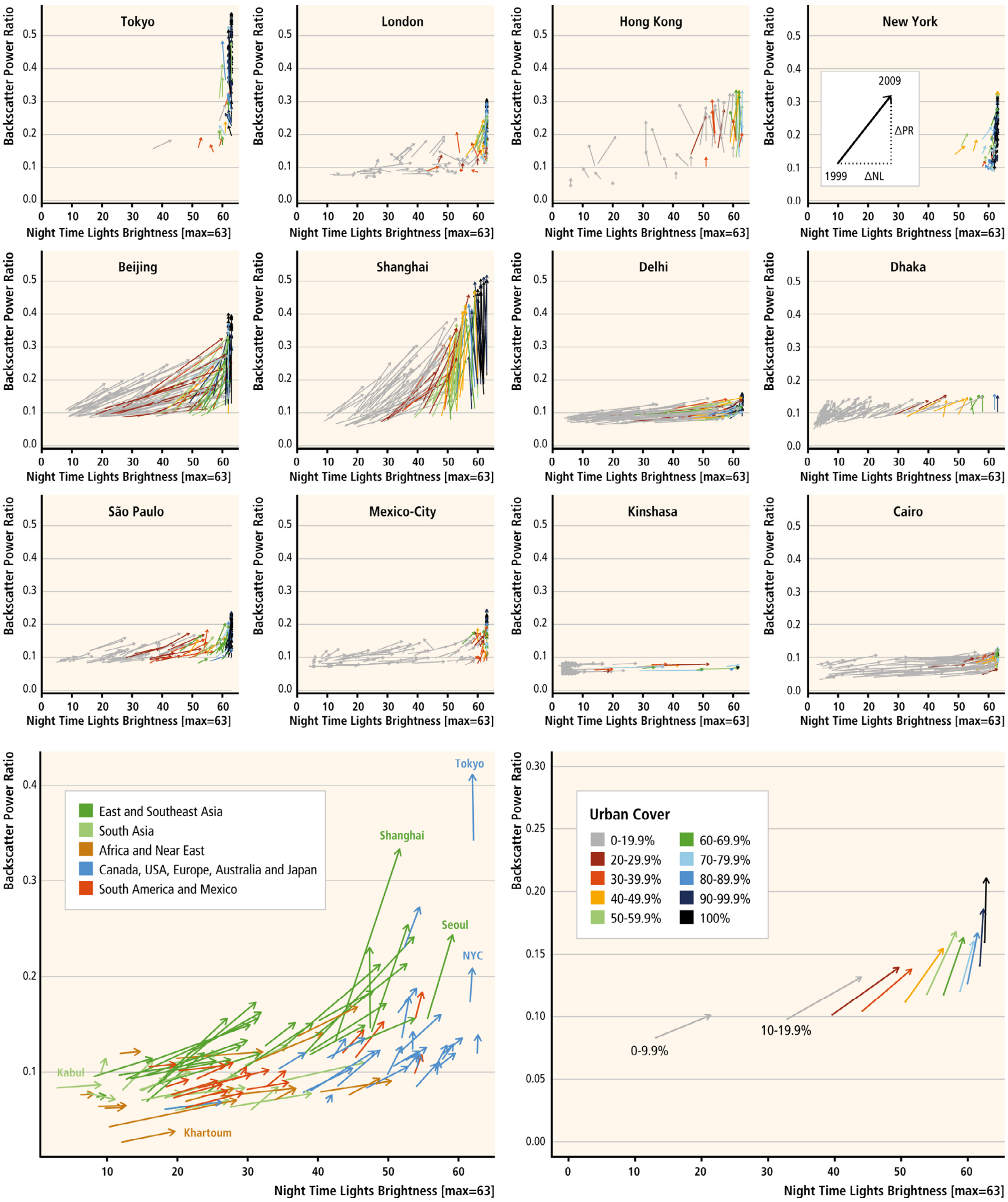


Figure 12.15. Changes in Urban Structure, 1999–2009 using backscatter and nighttime lights. The top 12 panels show changes in vertical structure of major urban areas as characterized by backscatter power ratio (PR) and horizontal growth as measured by night time lights brightness (NL) for 12 large cities. Coloured arrows represent non-water, 0.05° cells in an 11x11 grid around each city's centre; tail and head are at 1999 and 2009 coordinates of cell PR and NL, respectively (see inset in top right panel). Arrow colour corresponds to percent urban cover circa 2001 (see legend in bottom right panel). Bottom right panel shows mean change of a total of 100 cities mapping into the respective urban cover categories. Bottom left panel shows change for 100 cities colour coded by world regions. Source: (Frolking et al., 2013).

Medium-rise (less than seven floors) urban areas with a high building footprint ratio can have a higher built density than high-rise urban areas with a low building footprint. These different configurations of high-density development involve important energy tradeoffs. Often, high-rise, high-density urban areas involve a tradeoff between building height and spacing between buildings – higher buildings have to be more spaced out to allow light penetration. High-rise buildings imply higher energy costs in terms of vertical transport and also in 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). Single storey, free-standing housing units are more GHG emissions intensive than multi-family, semi-detached buildings (Myors et al., 2005; Perkins et al., 2009). Thus, while the effect of building type on energy use may be relatively small, the combination of dwelling type, design, location, and orientation together can generate significant energy savings (Rickwood et al., 2008).

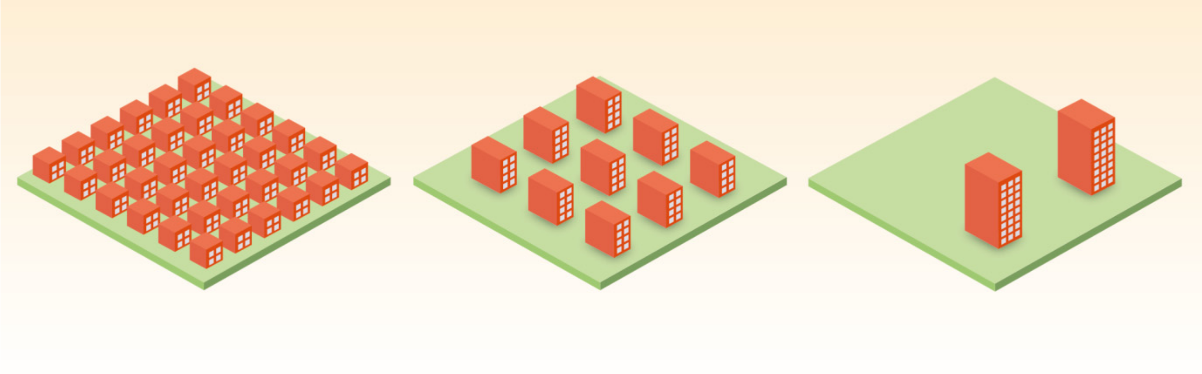


Figure 12.16. Same densities in three different layouts: low-rise single-story homes (left); multi-story medium-rise (middle); high-rise towers (right). Adapted from (Cheng, 2009).

12.4.2.2 Land use mix

Land use mix refers to the diversity and integration of land uses (e.g., residential, park, commercial) at a given scale (Figure 12.17). As with density, there are multiple measures of land use mix, including: (1) the ratio of jobs to residents; (2) the variety and mixture of amenities and activities; and (3) the relative proportion of retail and housing. Historically, the separation of land uses, especially of residential from other uses, was motivated by the noxious uses and pollution of the industrial city. However, as cities transition from industrial to service economies, resulting in a simultaneous reduction in air pollution and other nuisances, the rationale for such separation of land uses diminishes.

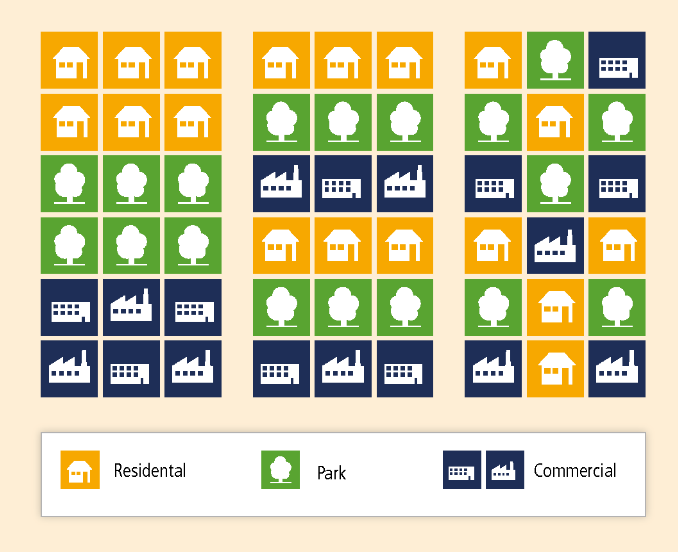


Figure 12.17. Three different land use mixes (Manaugh and Kreider, 2013).

In general, when land uses are separated, the distance between origin (e.g., homes) and destination (e.g., work or shopping) will be longer (Kockelman, 1997). Hence, diverse and mixed land uses can reduce travel distances and enable both walking and the use of non-motorized modes of travel (Kockelman, 1997; Permana et al., 2008), thereby reducing aggregate amounts of vehicular movement and associated greenhouse gas emissions (Lipper et al., 2010). Several meta-analyses estimate the elasticity of land use mix related VKT from -0.02 to -0.10 (Ewing and Cervero, 2010; Salon et al., 2012) while simultaneously increasing walking. The average elasticity between walking and diversity of land uses is reported to be between 0.15–0.25 (Ewing and Cervero, 2010). The effects of mixed land use on VKT and GHG emissions can applied at three spatial scales; city-regional, neighbourhood, and block.

At the city-scale, a high degree of land use mix can result in significant reductions in VKT by increasing the proximity of housing to office developments, business districts, shops, and malls (Cervero and Duncan, 2006). In service-economy cities with effective air pollution controls, mixed land use can also have a beneficial impact on citizen health and well-being by enabling walking and cycling (Saelens et al., 2003; Heath et al., 2006; Sallis et al., 2009). For cities with lower mixed land use, such as often found in North American cities and in many new urban developments in Asia, large residential developments are separated from jobs or retail centres by long distances. A number of studies of such single-use zoning show strong tendencies for residents to travel longer overall distances and to carry out a higher proportion of their travel in private vehicles than residents who live in mixed land use areas in cities (Mogridge, 1985; Fouchier, 1998; Næss, 2005; Zhou and Kockelman, 2008).

Mixed use at the neighbourhood scale refers to a 'smart' mix of residential buildings, offices, shops, and urban amenities (Bourdic et al., 2012). Similar to the city-scale case, such mixed uses can decrease average travel distances (McCormack et al., 2001). However, on the neighbourhood scale, the reduced travel is primarily related to non-work trips, e.g., for shopping, services, and leisure. Research on US cities indicates that the presence of shops and workplaces near residential areas is associated with relatively low vehicle ownership rates (Cervero and Duncan, 2006), and can have a positive impact on transportation patterns (Ewing and Cervero, 2010). The impacts of mixed use on non-motorized commuting such as cycling and walking and the presence or absence of neighbourhood shops can be even more important than urban density (Cervero, 1996).

At the block and building scale, mixed use allows space for small-scale businesses, offices, workshops, and studios that are intermixed with housing and live-work spaces. Areas with a high mix of land uses encourages a mix of residential and retail activity and thus increases the area's vitality, aesthetic interest, and neighbourhood (Hoppenbrouwer and Louw, 2005).

12.4.2.3 Connectivity

Connectivity refers to street density and design. Common measures of connectivity include intersection density or proportion, block size, or intersections per road kilometer (Cervero and Kockelman, 1997; Pushkar et al., 2000; Chapman and Frank, 2004; Lee and Moudon, 2006; Fan, 2007). Where street connectivity is high—characterized by finer grain systems with smaller blocks that allow frequent changes in direction—there is typically a positive correlation with walking and thereby lower GHG emissions. Two main reasons for this are that distances tend to be shorter and the system of small blocks promotes convenience and walking (Gehl, 2010).

Improving connectivity in areas where it is low (and thus associated with higher GHG emissions) requires varying amounts of street reconstruction. Many street features, such as street size, four-way intersections or intersection design, sidewalk width, the number of traffic lanes (or street width) and street medians are designed at the time of the construction of the city. As the infrastructure already exists, increasing connectivity requires investment either to redevelop the site or to retrofit it to facilitate walking and biking. In larger redevelopment projects, street patterns may be redesigned for smaller blocks with high connectivity. Alternatively, retrofitting often involves widening sidewalks, constructing medians, and adding bike lanes, as well as reducing traffic speeds, improving traffic signals, and providing parking for bikes (McCann and Rynne, 2010). Other features, such as street furniture (e.g., benches, transit stops, and shelters), street trees, and traffic signals, can be added after the initial design without much disruption or large costs.

Systematic reviews show that transport network connectivity has a larger impact on VKT than density or land use mix, between -0.06 and -0.26 (Ewing and Cervero, 2010; Salon et al., 2012). For North American cities, the elasticity of walking with respect to sidewalk coverage or length is between 0.09 to 0.27 (Salon et al., 2012). There are typically higher elasticities in other OECD countries than in the United States.

12.4.2.4 Accessibility

Accessibility can be defined as access to jobs, housing, services, shopping, and in general, to people and places in cities (Hansen, 1959; Ingram, 1971; Wachs and Kumagai, 1973). It can be viewed as a combination of proximity and travel time, and is closely related to land use mix. Common measures of accessibility include population centrality, job accessibility by auto or transit, distance to the city centre or central business district (CBD), and retail accessibility. Meta-analyses show that VKT reduction is most strongly related to high accessibility to job destinations (Ewing and Cervero, 2001, 2010). Highly accessible communities (e.g., compact cities in Europe such as Copenhagen) are typically characterized by low daily commuting distances and travel times, enabled by multiple modes of transportation (Næss, 2006). Measures to increase accessibility that are accompanied by innovative technologies and alternative energies can reduce VKT and associated GHG emissions in the cities of both developed and developing countries (Salomon and Mokhtarian, 1998; Axhausen, 2008; Hankey and Marshall, 2010; Banister, 2011). However, it should be noted that at least one study has shown that in cities where motorization is already mature, changing accessibility no longer influences automobile-dependent lifestyles and travel behaviours (Kitamura et al., 2001).

Countries and regions undergoing early stages of urbanization may therefore have a unique potential to influence accessibility, particularly in cases where income levels, infrastructure, and motorization trends are rapidly changing (Kumar, 2004; Chen et al., 2008; Perkins et al., 2009; Reilly et al., 2009; Zegras, 2010; Hou and Li, 2011; Adeyinka, 2013). In Shanghai, China, new transportation projects have influenced job accessibility and have thereby reduced commute times (Cervero and Day, 2008). In Chennai, India, differences in accessibility to the city centre between low-income communities have been shown to strongly affect transport mode choice and trip frequency

(Srinivasan and Rogers, 2005). In the rapidly motorizing city of Santiago de Chile, proximity to the central business district as well as metro stations has a relatively strong association with VKT (Zegras, 2010). The typical elasticity between job accessibility and VKT across North American cities ranges from -0.10 to -0.30 (Ewing and Cervero, 2010; Salon et al., 2012).

12.4.2.5 Effects of combined options

While individual measures of urban form have relatively small effects on vehicle miles travelled, they become more effective when combined. For example, there is consistent evidence that the combination of co-location of increased population and job densities, substantial investments in public transit, higher mix of land uses, and transportation or mobility demand management strategies can reduce VKT and travel-related carbon emissions (National Research Council, 2009a; Ewing and Cervero, 2010; Salon et al., 2012). The spatial concentration of population, coupled with jobs-housing balance, have a significant impact VKT by households. At the same time, urban form and the density of transportation networks also affect VKT (Bento et al., 2005). The elasticity of VKT with respect to each of these factors is relatively small, between 0.10 and 0.20 in absolute value. However, changing several measures of form simultaneously can reduce annual VKT significantly. Moving the sample households from a city with the characteristics of a low-density, automobile-centric city to a city with high public transit, connectivity, and mixed land use reduced annual VKT by 25%. While in practice such change is highly unlikely in a mature city, it may be more relevant when considering cities at earlier stages of development.

A growing body of literature shows that traditional neighbourhood designs are associated with reduced travel and resource conservation (Krizek, 2003; Ewing and Cervero, 2010). A US study found those living in neo-traditional neighbourhoods made as many daily trips as those in low-density, single-family suburban neighbourhoods, however the switch from driving to walking and the shortening of trip distances resulted in a 20% less VKT per household (Khattak and Rodriguez, 2005). Empirical research shows that the design of streets have even stronger influences than urban densities on incidences of walking and reduced motorized travel in traditional neighbourhoods of Bogota, Tehran, Taipei, and Hong Kong SAR (China) (Zhang, 2004; Cervero et al., 2009; Lin and Yang, 2009; Lotfi and Koohsari, 2011). A study in Jinan, China, found the energy use of residents living in mixed-use and grid street enclaves to be one-third that of similar households in superblock, single-use developments (Calthorpe, 2013).

12.5 Spatial Planning and Climate Change Mitigation

Spatial planning is a broad term that describes systematic and coordinated efforts to manage urban and regional growth in ways that promote well-defined societal objectives such as land conservation, economic development, carbon sequestration, and social justice. Growth management is a similar idea, aimed at guiding “the location, quality, and timing of development” (Porter, 1997) to minimize ‘sprawl’ (Nelson and Duncan, 1995), which is characterized by low density, non-contiguous, automobile-dependent development that prematurely or excessively consumes farmland, natural preserves, and other valued resources (Ewing, 1997).

This section reviews the range of spatial planning strategies that may reduce emissions through impacts on most if not all of the elements of urban form and infrastructure reviewed in Section 12.4. It begins with an assessment of key spatial planning strategies that can be implemented at the macro, meso, and micro geographic scales. It then assesses the range of regulatory, land use, and market-based policy instruments that can be employed to achieve these strategic objectives. Given evidence of the increased emissions reduction potential associated with affecting the collective set of spatial factors driving emissions (see Section 12.4), emphasis is placed on assessing the efficacy of strategies or bundles that simultaneously impact multiple spatial outcomes (See Chapter 15.4 and 15.5 on policy evaluation and assessment).

The strategies discussed below aim to reduce sprawl and automobile dependence–and thus energy consumption, VKT, and GHG emissions–to varying degrees. Evidence on the energy and emission reduction benefits of these strategies comes mainly from case studies in the developed world even though their greatest potential for reducing future emissions lies in developing countries undergoing early stages of urbanization. The existing evidence highlights the importance of an integrated infrastructure development framework that combines analysis of mitigation reduction potentials alongside the long-term public provision of services.

Box 12.3. Urban expansion: drivers, markets, and policies

While the literature that examines the impacts of changes in urban spatial structure and infrastructure on urban GHG emissions is sparse, there is a well-established body of literature that discusses the drivers of urban development, and policies that aim to alter its pace and shape.

- **Drivers of Urban Expansion** – The drivers of urban development can be broadly defined into the following categories: *Economic Geography, Income, Technology* (see Section 12.3.1), as well as *Market Failures* (see Chapter 15), and *Pre-Existing Conditions,* which are structured by *Policies and Regulations* (see Section 12.5.2) that in turn shape *Urban Form and Infrastructure* (see Section 12.4 and Box 12.4).

- **Primary drivers** of urban spatial expansion unfold under the influence of economic conditions and the functioning of markets. These are however strongly affected by **Market Failures** and **Pre-Existing Policies and Regulations** that can exacerbate or alleviate the effect of the primary drivers on urban growth.

- **Market Failures** are the result of individuals and firms ignoring the external costs and benefits they impose on others when making economic decisions (see Chapter 15). These include:
    - Failure to account for the social costs of GHG (and local) emissions that result from production and consumption activities in cities.
    - Failure to account for the social costs of traffic congestion (see Chapter 8).
    - Failure to assign property rights and titles for land.
    - Failure to account for the social benefits of spatial amenities and mix land uses (see Section 12.5.2.3).
    - Failure to account for the social benefits of agglomeration that result from the interactions of individuals and firms in cities.

- Although not precisely quantified in the literature, by altering the location of individuals and firms in space (and resulting travelling patterns and consumption of space), these market failures can lead to excessive growth (see Box 12.4).

- For each failure, there is a policy solution, either in the form of regulations or market-based instruments (see Section 12.5.2)

- **Pre-Existing Policies and Regulations** can also lead to excessive growth. These include:
    - **Hidden Pre-Existing Subsidies** – including the failure to charge new development for the infrastructure costs it generates (see Section 12.5.3 and Box 12.4).
    - **Outdated or Poorly Designed Pre-Existing Policies and Regulations** - including zoning, building codes, ordinances, and property taxes that can distort real estate markets (see Section 12.5.2 and Box 12.4).

12.5.1 Spatial Planning Strategies

Spatial planning occurs at multiple geographic scales: (1) Macro – regions and metropolitan areas; (2) Meso – sub-regions, districts, and corridors; and (3) Micro – neighbourhoods, streets, blocks. At each scale, some form of comprehensive land-use and transportation planning provides a different opportunity to envision and articulate future settlement patterns, backed by zoning ordinances, subdivision regulations, and capital improvements programmes to implement the vision (Hack et al., 2009). Plans at each scale must also be harmonized and integrated to maximize effectiveness and efficiency (Hoch et al., 2000). Different strategy bundles invite different policy tools, adapted to the unique political, institutional, and cultural landscapes of cities in which they are applied (see Table 12.5). Successful implementation requires that there be in place the institutional capacity and political wherewithal to align the right policy instruments to specific spatial planning strategies.

12.5.1.1 Macro: Regions and metropolitan areas

Macro-scale strategies are regional in nature, corresponding to the territories of many economic transactions (e.g., laboursheds and tradesheds) and from where natural resources are drawn (e.g., water tributaries) or externalities are experienced (e.g., air basins).

Regional Plan. A regional plan shows where and when different types of development are allowed, and where and when they are not. In polycentric plans, sub-centres often serve as building blocks for designing regional rail-transit networks (Calthorpe and Fulton, 2001). Scale is a particularly important determinant of success. Regional strategies can minimize environmental spillovers and economize on large-scale infrastructure investments (Calthorpe and Fulton, 2001; Seltzer and Carbonell, 2011). Polycentric metropolises like Singapore, Tokyo, and Paris have successfully linked sub-centres with high-quality, synchronized metro-rail and feeder bus services (Cervero, 1998; Gakenheimer, 2011). Spatial plans might be defined less in terms of a specific urban-form vision and more with regard to core development principles. In its 'Accessible Ahmedabad' plan, the city of Ahmedabad, India, embraced the principle of creating a city designed for accessibility rather than mobility, without specific details on the siting of new growth (Suzuki et al., 2013).

Urban containment. Urban containment encourages cities and their peripheries to grow inwards and upwards, not outwards (Pendall et al., 2002). Urban containment can also contribute to climate change mitigation by creating more compact, less car-oriented built form as well as by preserving the carbon sequestration capacity of natural and agricultural areas in the surrounding areas (Daniels, 1998). The impact of development restrictions is uncertain and varies with the geographic and regulatory context (Pendall, 1999; Dawkins and Nelson, 2002; Han et al., 2009; Woo and Guldmann, 2011). In the United States, regional measures such as the Portland urban growth boundary have been more effective at containing development than local initiatives (DeGrove and Miness, 1992; Nelson and Moore, 1993; Boyle and Mohamed, 2007). In the UK, urban containment policies may have pushed growth to leapfrog the greenbelt to more distant locations and increased car commuting (Amati, 2008). In Seoul and in Swiss municipalities, greenbelts have densified the core city but made the metropolitan area as a whole less compact; in Seoul, commuting distances also increased by 5% (Jun and Bae, 2000; Bae and Jun, 2003; Bengston and Youn, 2006; Gennaio et al., 2009).

Regional jobs-housing balance. Separation of workers from job sites creates long-haul commutes and thus worsens traffic and environmental conditions (Cervero, 1996). Jobs-housing imbalances are often a product of insufficient housing in jobs-rich cities and districts (Boarnet and Crane, 2001; Wilson, 2009; Pendall et al., 2012). One view holds that the market will eventually work around such problems–developers will build more housing near jobs because more profit can be made from such housing (Gordon et al., 1991; Downs, 2004). There is evidence of co-location in US cities like Boston and Atlanta (Weitz, 2003). Even in the developing world, co-location occurs as a means to economize on travel, such as the peri-urban zones of Dar es Salaam and Lagos where infill and densification, often in the form of informal settlements and shantytowns, occurs in lieu of extended growth along peripheral radial roads (Pirie, 2011).

Research on balanced growth strategies provides mixed signals on mobility and environmental impacts. Studies of Atlanta estimate that jobs-housing balance can reduce traffic congestion, emissions, and related externalities (Weitz, 2003; Horner and Murray, 2003). In the San Francisco

Bay Area, jobs-housing balance has reduced travel more than intermixing housing and retail development (Cervero and Duncan, 2006) Other studies, however, suggest that jobs-housing balance has little impact on travel and traffic congestion since many factors besides commuting condition residential location choices (Levine, 1998).

Self-contained, ‘complete’ communities—wherein the jobs, retail commodities and services needed by workers and households exist within a community—is another form of balanced growth. Many master-planned new towns in the United States, France, South Korea, and the UK were designed as self-contained communities, however their physical isolation and economic dependence on major urban centres resulted in high levels of external motorized travel (Cervero, 1995a; Hall, 1996). How new towns are designed and the kinds of transport infrastructure built, experiences show, have strongly influenced travel and environmental outcomes (Potter, 1984). In the UK, new towns designed for good transit access (e.g., Runcorn and Redditch) averaged far higher transit ridership and less VKT per capita than low-density, auto-oriented communities like Milton Keynes and Washington, UK (Dupree, 1987).

Telecommunities are a more contemporary version of self-contained communities, combining information and communication technologies (ICTs) with traditional neighbourhood designs in remote communities on the edges of cities like Washington, DC and Seattle (Slabbert, 2005; Aguilera, 2008). Until such initiatives scale up, their contributions to VKT and GHG reductions will likely remain miniscule (Choo et al., 2005; Andreev et al., 2010; Mans et al., 2012
nnnnb).

Table 12.5. Matching spatial planning strategies and policy instruments. Summary of the types of policy instruments that can be applied to different spatial planning strategies carried out at different geographic scales. Unless otherwise noted, references can be found in the relevant chapter sections.

Additional sources referenced in table: 1 (Nelson, 1992; Alterman, 1997), 2 (Sagalyn, 2007; Yescombe, 2007),3 (Hagman and Misczynski, 1978; Bauman and Ethier, 1987), 4 (Rolon, 2008), 5 (Dye and Sundberg, 1998; Dye and Merriman, 2000; Brueckner, 2001b),6 (Sælensminde, 2004; McAndrews et al., 2010), 7 (Rolon, 2008), 8 (Brambilla and Longo, 1977).

	POLICY INSTRUMENTS/IMPLEMENTATION TOOLS					
	Government Regulations		**Government Incentives**		**Market-Based Strategies**	
SPATIAL STRATEGY	**Land Regulation/Zoning** (see 12.5.2.1)	**Taxation/Finance Strategies** (see 12.5.2.3)	**Land Management** (see 12.5.2.2)	**Targeted Infrastructure/Services** (see 12.5.1)	**Pricing** (see 12.5.2.3)	**Public Private Partnerships** (see 12.5.2.3)
Metropolitan/Regional						
Urban containment	Development restrictions; UGBs	Sprawl taxes	Urban Service Boundaries	Park improvements; trail improvements		
Balanced growth	Affordable housing mandates	Tax-bases sharing	Extraterritorial zoning		Farm Tax Credits[1]	
Self-contained communities/ new towns	Mixed-use zoning		Greenbelts	Utilities; urban services		Joint ventures[2]
Corridor/District						
Corridor growth management	Zoning	Impact fees; Exactions[3]		Service Districts[4]		
Transit-oriented corridors	Transfer development rights			Urban rail; Bus rapid transit investments		Joint Powers Authorities
Neighbourhood/Community						
Urban Regeneration/Infill	Mix-use zoning/small lot designations	Split-Rate Property Taxes; Tax increment finance[5]	Redevelopment districts	Highway conversions; Context-sensitive design standards	Congestion charges (see Ch. 8)	
Traditional Neighbourhood Designs; New urbanism	Zoning overlays; form-based codes			Sidewalks; cycle tracks; bike stations[6]		
Transit oriented Development	Design codes; flexible parking	Impact Fees; Betterment Taxes[7]		Station siting; station access		Joint development[2]
Eco-Communities	Mixed-use zoning			District Heating/Cooling; co-generation (see Ch. 9.4)	Peak-load pricing	Joint venture[2]
Site/Streetscape						
Pedestrian Zones/Car-Free Districts	Street code revisions[8]	Special Improvement Districts[7]		Road entry restrictions; sidewalks[8]	Parking surcharges	
Traffic Calming/Context-Sensitive Design	Street code revisions[8]	Benefit Assessment[7]				Property owner self-assessments
Complete Streets	Design standards			Bike infrastructure; Pedestrian facilities		Design competitions

12.5.1.2 Meso: Sub-regions, corridors, and districts

The corridor or district scale captures the spatial context of many day-to-day activities, such as going to work or shopping for common household items. Significant challenges are often faced in coordinating transportation and land development across multiple jurisdictions along a corridor.

Corridor growth management. Corridor-level growth management plans aim to link land development to new or expanded infrastructure investments (Moore et al., 2007). Both land development and transport infrastructure need years to implement, so coordinated and strategic long-range planning is essential (Gakenheimer, 2011). Once a transport investment is committed and land use policies are adopted, the two can co-evolve over time. A good example of coordinated multi-jurisdictional management of growth is the 20 km Paris-Pike corridor outside of Lexington, Kentucky in the United States (Schneider, 2003). There, two county governments reached an agreement and created a new extra-territorial authority to zone land parcels for agricultural activities within a 0.5 km radius of a newly expanded road to preserve the corridor's rural character, prevent sprawl, and maintain the road's mobility function.

Transit-oriented corridors. Corridors also present a spatial context for designing a network of Transit Oriented Developments (TODs), traditional (e.g., compact, mixed-use, and pedestrian-friendly) development that is physically oriented to a transit station. TODs are expected to reduce the need to drive, and thus reduce VKT. Some global cities have directed land uses typically scattered throughout suburban developments (e.g., housing, offices, shops, restaurants, and strip malls) to transit-served corridors (Moore et al., 2007; Ferrell et al., 2011). Scandinavian cities like Stockholm, Helsinki, and Copenhagen have created 'necklace of pearls' built form not only to induce transit riding but also to produce balanced, bi-directional flows and thus more efficient use of infrastructure (Cervero, 1998; Suzuki et al., 2013).

Curitiba, Brazil, is often heralded as one of the world's most sustainable cities and is a successful example of the use of Transit Oriented Corridors (TOCs) to shape and direct growth (Cervero, 1998; Duarte and Ultramari, 2012). The city has evolved along well-defined radial axes (e.g., lineal corridors) that are served by dedicated busways. Along some transportation corridors, double-articulated buses transport about 16,000 passengers per hour, which is comparable to the capacity of more expensive metro-rail systems (Suzuki et al., 2013). To ensure a transit-oriented built form, Curitiba's government mandates that all medium- and large-scale urban development be sited along a Bus Rapid Transit (BRT) corridor (Cervero, 1998; Hidalgo and Gutiérrez, 2013). High transit use has appreciably shrunk the city's environmental footprint. In 2005, Curitiba's VKT per capita of 7,900 was half as much as in Brazil's national capital Brasilia, a city with a similar population size and income level but a sprawling, auto-centric built form (Santos, 2011).

12.5.1.3 Micro: communities, neighbourhoods, streetscapes

The neighbourhood scale is where activities like convenience shopping, socializing with neighbours, and walking to school usually take place, and where urban design approaches such as gridded street patterns and transit-oriented development are often targeted. While smaller scale spatial planning might not have the energy conservation or emission reduction benefits of larger scale planning strategies, development tends to occur parcel-by-parcel and urbanized areas are ultimately the products of thousands of individual site-level development and design decisions.

Urban Regeneration and Infill Development. The move to curb urban sprawl has spawned movements to revitalize and regenerate long-standing traditional urban centres (Oatley, 1995). Former industrial sites or economically stagnant urban districts are often fairly close to central business districts, offering spatial proximity advantages. However, brownfield redevelopment (e.g., tearing down and replacing older buildings, remediating contaminated sites, or upgrading worn out or obsolete underground utilities) can often be more expensive than building anew on vacant greenfield sites (Burchell et al., 2005).

In recent decades, British planners have turned away from building expensive, master-planned new towns in remote locations to creating 'new towns/in town', such as the light-rail-served Canary Wharf brownfield redevelopment in east London (Gordon, 2001). Recycling former industrial estates into mixed-use urban centres with mixed-income housing and high-quality transit services have been successful models (Foletta and Field, 2011). Vancouver and several other Canadian cities have managed to redirect successfully regional growth to their urban cores by investing heavily in pedestrian infrastructure and emphasizing an urban milieu that is attractive to families. In particular, Vancouver has invested in developing attractive and inviting urban spaces, high quality and dedicated cycling and walking facilities, multiple and reliable public transit options, and creating high-density residential areas that are integrated with public and cooperative housing (Marshall, 2008). Seoul, South Korea, has sought to regenerate its urban core through a mix of transportation infrastructure investments and de-investments, along with urban renewal (Jun and Bae, 2000; Jun and Hur, 2001). Reclaiming valuable inner-city land in the form of tearing down an elevated freeway and expropriating roadway lanes, replaced by expanded BRT services and pedestrian infrastructure has been the centrepiece of Seoul's urban regeneration efforts (Kang and Cervero, 2009).

Traditional neighbourhood design and new urbanism. Another movement, spearheaded by reform-minded architects and environmental and sustainability planners, has been to return communities to their designs and qualities of yesteryear, before the ascendency of the private automobile (Nasar, 2003). Referred to as 'compact cities' in much of Europe and 'New Urbanism' in the United States, the movement takes on features of traditional, pre-automobile neighbourhoods that feature grid iron streets and small rectilinear city blocks well suited to walking, narrow lots and building setbacks, prominent civic spaces that draw people together (and thus help build social capital), tree-lined narrow streets with curbside parking and back-lot alleys that slow car traffic, and a mix of housing types and prices (Kunstler, 1998; Duany et al., 2000; Talen, 2005).

In the United States, more than 600 New Urbanism neighbourhoods have been built, are planned, or are under construction (Trudeau, 2013). In Europe, a number of former brownfield sites have been redeveloped since the 1980s based on traditional versus modernist design principles (Fraker, 2013). In developing countries, recent examples of neighbourhood designs and redevelopment projects that follow New Urbanism principles to varying degrees are found in Belize, Jamaica, Bhutan, and South Africa (Cervero, 2013).

Transit Oriented Development (TOD). TODs can occur at a corridor scale, as discussed earlier for cities like Curitiba and Stockholm, or as is more common, take on a nodal, neighbourhood form. Besides being the 'jumping off' point for catching a train or bus, TODs also serve other community purposes. Scandinavian TODs often feature a large civic square that functions as a community's hub and human-scale entryway to rail stations (Bernick and Cervero, 1996; Curtis et al., 2009).

In Stockholm and Copenhagen, TOD has been credited with reducing VKT per capita to among the lowest levels anywhere among high-income cities (Newman and Kenworthy, 1999). In the United States, studies show that TODs can decrease per capita use of cars by 50%. In turn, this could save households about 20% of their income (Arrington and Cervero, 2008). TOD residents in the United States typically commute by transit four to five times more than the average commuter in a region (Lund et al., 2006). Similar ridership bonuses have been recorded for TOD projects in Toronto, Vancouver, Singapore, and Tokyo (Chorus, 2009; Yang and Lew, 2009). In China, a recent study found smaller differentials of around 25% in rail commuting between those living near, versus away from suburban rail stations (Day and Cervero, 2010).

Many cities in the developing world have had long histories of being transit oriented, and feature fine-grain mixes of land uses, abundant pathways that encourage and enable walking and biking, and ample transit options along major roads (Cervero, 2006; Cervero et al., 2009; Curtis et al., 2009). In Latin America, TOD is being planned or has taken form to varying degrees around BRT stations in Curitiba, Santiago, Mexico City, and Guatemala City. TOD is also being implemented in Asian cities, such as in Kaohsiung, Qingdao and Jiaxing, China, and Kuala Lumpur, Malaysia (Cervero, 2013). Green TODs that feature low-energy/low-emission buildings and the replacement of surface parking with community gardens are being built (Teriman et al., 2010; Cervero and Sullivan, 2011). A number of Chinese cities have embraced TOD for managing growth and capitalizing upon massive rail and BRT investments. For example, Beijing and Guangzhou adopted TOD as a guiding design principle in their most recent long-range master plans (Li and Huang, 2010). However, not all have succeeded. TOD efforts in many Chinese cities have been undermined by a failure to articulate densities (e.g., tapering building heights with distances from stations), the siting of stations in isolated superblocks, poor pedestrian access, and a lack of co-benefiting mixed land uses (Zhang, 2007; Zhang and Wang, 2013).

Pedestrian zones/car-restricted districts. Many European cities have elevated liveability and pedestrian safety to the top of transportation planning agendas, and have invested in programmes that reduce dependence on and use of private automobiles (Banister, 2005, 2008; Dupuy, 2011). One strategy for this is traffic calming, which uses speed humps, realigned roads, necked down intersections along with planted trees and other vegetation in the middle of streets to slow down traffic (Ewing and Brown, 2009). With these traffic calming approaches, automobile passage becomes secondary. A related concept is 'complete streets,' which—through dedicated lanes and traffic-slowing designs—provide safe passage for all users of a street, including drivers as well as pedestrians, cyclists, and transit patrons (McCann and Rynne, 2010).

An even bolder urban-design/traffic-management strategy has been the outright banning of cars from the cores of traditional neighbourhoods and districts, complemented by an upgrading and beautification of pedestrian spaces. This practice has become commonplace in many older European cities whose narrow and winding inner-city street were never designed for motorized traffic (Hass-Klau, 1993). Multi-block car-free streets and enhanced pedestrian zones are also found in cities of the developing world, including Curitiba, Buenos Aires, Guadalajara, and Beirut (Cervero, 2013).

Empirical evidence reveals a host of benefits from street redesigns and auto-restraint measures like these. The traffic-calming measures implemented in Heidelberg, Germany during the early 1990s lead to a 31% decline in car-related accidents, 44% fewer casualties, and less central-city traffic (Button, 2010). A study of pedestrianization in German cities recorded increases in pedestrian flows, transit ridership, land values, and retail transactions, as well as property conversions to more intensive land uses, matched by fewer traffic accidents and fatalities (Hass-Klau, 1993). Research on over 100 case studies in Europe, North America, Japan, and Australia, found that road-capacity reductions including car-free zones, creation of pedestrian streets, and street closures, results in an overall decline in motorized traffic of 25% (Goodwin et al., 1998).

12.5.2 Policy Instruments

Spatial planning strategies rely on a host of policy instruments and levers (see Chapter 15.3 for a classification of policy instruments). Some instruments intervene in markets, aimed at correcting market failures (e.g., negative externalities). Others work with markets, aimed at shaping behaviours through price signals or public-private partnerships. Interventionist strategies can discourage or restrict growth through government fiat but they can also incentivize development, such as through zoning bonuses or property tax abatements (Bengston et al., 2004). Policy instruments can be applied to different spatial planning strategies and carried out at different geographic scales (see Table 12.5). Different strategy bundles can be achieved through a mix of different policy tools, adapted to the unique political, institutional, and cultural landscapes of cities in which they are applied. Successful implementation requires institutional capacity and political wherewithal to align the right policy instruments to specific spatial planning strategies.

The effectiveness of particular instruments introduced depends on legal and political environments. For example, cities in the Global South can lack the institutional capacity to regulate land or to enforce development regulations and tax incentives may have little impact on development in the informal sector (Farvacque and McAuslan, 1992; Sivam, 2002; Bird and Slack, 2007; UN-Habitat, 2013). Infrastructure provision and market-based instruments such as fuel taxes will more likely affect development decisions in the informal sectors, although there is little direct empirical evidence. The impact of instruments on urban form and spatial outcomes can be difficult to assess since regulations like land-use zoning are often endogenous. That is, they codify land use patterns that would have occurred under the free market rather than causing changes in urban form (Pogodzinski and Sass, 1994).

12.5.2.1 Land use regulations

Land-use regulations specify the use, size, mass and other aspects of development on a particular parcel of land. They are also known as development controls or zoning regulations. In countries like the United States and India, land-use regulations usually promote low-density, single-use developments with large amounts of parking that increase car dependence and emissions (Talen 2012; Levine 2005; Glaeser, 2011). For example, densities in the United States are often lower than developers would choose under an unregulated system (Fischel, 1999; Levine and Inam, 2004). Thus, regulatory reforms that relax or eliminate overly restrictive land-use controls could contribute to climate change mitigation. In Europe, by contrast, land-use regulations have been used to promote more compact, mixed-use, transit-friendly cities (Beatley, 2000). The following are the primary land-use regulations to reduce urban form-related GHG emissions.

Use restrictions specify which land uses, such as residential, retail or office, or a mix of uses, may be built on a particular parcel. Single-use zoning regulations which rigidly separate residential and other uses are prevalent in the United States, although some cities such as Miami have recently adopted form-based codes which regulate physical form and design rather than use (Parolek et al., 2008; Talen, 2012). Use restrictions are rare in European countries such as Germany and France, where mixed-use development is permitted or encouraged (Hirt, 2007, 2012).

Density regulations specify minimum and/or maximum permissible densities in terms of the number of residential units, floor area on a parcel, or restrictions on building height or mass. Density regulations can provide incentives for open space or other public benefits by allowing higher density development in certain parts of a city. In India, densities or heights are capped in many cities, creating a pattern of mid-rise buildings horizontally spread throughout the city and failing to allow TOD to take form around BRT and urban rail stations (Glaeser, 2011; Brueckner and Sridhar, 2012; Suzuki et al., 2013). In Europe, by contrast, land-use regulations have been used to promote more compact, mixed-use, transit-friendly cities (Beatley, 2000; Parolek et al., 2008; Talen, 2012). In Curitiba, Brazil, density bonuses provide incentives for mixed-use development (Cervero, 1998; Duarte and Ultramari, 2012). A density bonus (Rubin and Seneca, 1991) is an option where an incentive is created for the developer to set aside land for open spaces or other benefits by being allowed to develop more densely, typically in CBDs. One challenge with density bonus is that individuals may have preferences for density levels (high, low) and adjust their location accordingly.

Urban containment instruments include greenbelts or urban growth boundaries and have been employed in London, Berlin, Portland, Beijing, and Singapore. In the UK and in South Korea, greenbelts delineate the edges of many built-up and rural areas (Hall, 1996; Bengston and Youn, 2006). In many European cities, after the break-up of the city walls in the 18th and 19th centuries, greenbelts were used to delineate cities (Elson, 1986; Kühn, 2003). Some US states have passed growth management laws that hem in urban sprawl through such initiatives as creating urban growth boundaries, geographically restricting utility service districts, enacting concurrency rules to pace the rate of land development and infrastructure improvements, and tying state aid to the success of local governments in controlling sprawl (DeGrove and Miness, 1992; Nelson et al., 2004). The mixed evidence on the impacts of urban containment instruments on density and compactness (decreases in some cases and increases in others) indicates the importance of instrument choice and particularities of setting.

Building codes provide a mechanism to regulate the energy efficiency of development. Building codes affect the energy efficiency of new development, and cities provide enforcement of those regulations in some countries (Chapter 9). City policies influence emissions through energy use in buildings in several other ways, which can influence purchases and leasing of commercial and residential real estate properties. Some cities participate in energy labelling programmes for buildings (see Chapter 9.10.2.6) or have financing schemes linked to property taxes (see Property Assess Clean Energy (PACE) in Chapter 9.10.3.1). Energy efficient equipment in buildings can further reduce energy consumption and associated emissions, including electronics, appliances, and equipment (see Table 9.3). Cities that operate utilities can influence energy usage directly by using smart meters and information infrastructures (see 9.4.1.3).

Parking regulations specify minimum and/or maximum numbers of parking spaces for a particular development. Minimum parking standards are ubiquitous in much of the world, including cities in the United States, Mexico, Saudi Arabia, Malaysia, China, and India (Barter, 2011; Al-Fouzan, 2012; Wang and Yuan, 2013). Where regulations require developers to provide more parking than they would have otherwise, as in place like New York and Los Angeles (McDonnell et al., 2011; Bowman and Franco, 2012), they induce car travel by reducing the cost of driving. Minimum parking requirements also have an indirect impact on emissions through land-use, as they reduce the densities that are physically or economically feasible on a site, by 30%–40% or more in typical cases in the United States (Willson, 1995; Talen, 2012). Maximum parking standards, in contrast, have been used in cities such as San Francisco, London, and Zurich (Kodransky and Hermann, 2011) to reduce the costs of development, use urban land efficiently, and encourage alternate transportation modes. In London, moving from minimum to maximum residential parking standards reduced parking supply by 40%, with most of the impact coming through the elimination of parking minimums (Guo and Ren, 2013).

Design regulations can be used to promote pedestrian and bicycle travel. For example, site-design requirements may require buildings to face the street or prohibit the placement of parking between building entrances and street rights-of-way (Talen, 2012). Design regulations can also be used to increase albedo or reduce urban heat island effects, through requiring light-coloured or green roofs or regulating impervious surfaces (Stone et al., 2012), as in Montreal and Toronto (Richardson and Otero, 2012).

Affordable housing mandates can reduce the spatial mismatch between jobs and housing (Aurand, 2010)**.** Incentives, such as floor area ratios and credits against exactions and impact fee obligations, can be arranged for developers to provide social housing units within their development packages (Cervero, 1989; Weitz, 2003).

Box 12.4. What drives declining densities?

The global phenomenon of declining densities (Angel et al., 2010) is the combined result of (1) fundamental processes such as population growth, rising incomes, and technological improvements in urban transportation systems (LeRoy and Sonstelie, 1983; Mieszkowski and Mills, 1993; Bertaud and Malpezzi, 2003; Glaeser and Kahn, 2004); (2) market failures that distort urban form during the process of growth (Brueckner, 2001a; Bento et al., 2006, 2011); and (3) regulatory policies that can have unintended impacts on density (Sridhar, 2007, 2010). A range of externalities can result in lower densities, such as the failure to adequately account for the cost of traffic congestion and infrastructure development and the failure to account for the social value of open space (Brueckner, 2000).

Regulatory policies, such as zoning and Floor Area Ratio (FAR) restrictions, as well as subsidies to particular types of transportation infrastructures can have large impacts on land development, which lead to leapfrog development (Mieszkowski and Mills, 1993; Baum-Snow, 2007; Brueckner and Sridhar, 2012). The emissions impacts of these interventions are often not fully understood. Finally, the spatial distribution of amenities and services can shape urban densities through housing demand (Brueckner et al., 1999). In the United States, deteriorating conditions in city centres have been an important factor in increased suburbanization (Bento et al., 2011; Brueckner and Helsley, 2011). Conversely, the continued consolidation of amenities, services, and employment opportunities in the cores of European and Chinese cities has kept households in city centres (Brueckner et al., 1999; Zheng et al., 2006, 2009).

12.5.2.2 Land management and acquisition

The previous section discussed regulatory instruments that are primarily used to shape the decisions of private landowners. Land management and acquisition include parks, lease air rights, utility corridors, transfer development rights, and urban service districts. Urban governments can also directly shape urban form through land that is publicly owned – particularly around public transport nodes, where municipalities and public transport agencies have acquired land, assembled parcels, and taken the lead on development proposals (Cervero et al., 2004; Curtis et al., 2009; Curtis, 2012). In Hong Kong SAR, China, the 'Rail + Property' development programme, which emphasizes not only density but also mixed uses and pedestrian linkages to the station, increases patronage by about 35,000 weekday passengers at the average station. In addition to supporting ridership, an important aim of many agencies is to generate revenue to fund infrastructure, as in Istanbul, Sao Paulo, and numerous Asian cities (Peterson, 2009; Sandroni, 2010).

Transfer of Development Rights (TDR) allows the voluntary transfer or sale of development from one region or parcel where less development is desired to another region or parcel where more development is desired. They can be used to protect heritage sites from redevelopment or to redistribute urban growth to transit station areas. The parcels that 'send' development are protected through restrictive covenants or permanent conservation easements. TDR effectively redirects new growth from areas where current development is to be protected (historical sites or protected areas) to areas where more development is desired (e.g., transit station areas).

Increasing green space and urban carbon sinks can sequester carbon and reduce energy consumption for cooling. Increasing green space offers co-benefits such as increased property values, regulating stormwater, reduced air pollution, increased recreational space, provision of shade and cooling, rainwater interception and infiltration, increased biodiversity support, and enhancement of well-being (Heynen et al., 2006; Gill et al., 2007; McDonald, 2008). However, many studies show that significantly increasing urban green space would have negligible effects on offsetting total urban carbon emissions, especially when emissions generated by fuel combustion, fertilizer use, and irrigation are also considered (Pataki et al., 2009; Jim and Chen, 2009; Townsend-Small and Czimczik, 2010). Globally, urban soils could sequester 290 Mt carbon per year if designed with calcium-rich minerals (Renforth et al., 2009). Annual carbon uptake varies significantly by location and plant species. Carbon uptake per hectare for temperate urban green spaces is estimated to be 0.15–0.94 t/yr for seven cities in the United States: Atlanta, Baltimore, Boston, Jersey City, New York, Philadelphia, and Syracuse (Nowak and Crane, 2002); 0.38 t/yr in Beijing, China (Yang and Gakenheimer, 2007); and 0.53–0.8 t/yr in the South Korean cities of Chuncheon, Kangleung (Gangneung) and Seoul (Jo, 2002). United States cities in semi-tropical areas have higher levels of per hectare annual C sequestration, of 3.2 t/yr in Gainesville and 4.5 t/yr in Miami-Dade (Escobedo et al., 2010). Urban forests are estimated to sequester 1.66 (t C/ha)/yr in Hangzhou, China (Zhao et al., 2010). The variation in estimates across cities can be partly ascribed to differences in tree species, sizes, and densities of planting (Zhao et al., 2010), as well as land use (Whitford et al., 2001) and tree life span (Strohbach et al., 2012; Raciti et al., 2012).

12.5.2.3 Market-based instruments

Market-based instruments use taxation and pricing policies to shape urban form (see Chapter 15.5.2 for more in-depth discussion of market-based instruments). Because much low-density, single-use urban development stems from market failures or pre-existing distorted policies or regulations, a variety of market-based instruments can be introduced that correct these failures (Brueckner and Fansler, 1983; Brueckner and Kim, 2003; Brueckner, 2000; Bento et al., 2006, 2011).

Property taxes. The property tax, a local tax widely used to fund local urban services and infrastructure, typically taxes both land and structures. A variant of the property tax, a land tax or split-rate tax, levies a higher rate of tax on the value of the land, and a lower or zero rate on the value of the buildings and other improvements. This variant of the property tax can promote compact urban form through increasing the capital to land ratio, i.e., the intensity of development. There are numerous examples of the land or split-rate tax worldwide, including Jamaica, Kenya, Denmark, parts of Australia, the United States, and South Africa (Bird and Slack, 2002, 2007; Franzsen and Youngman, 2009; Banzhaf and Lavery, 2010) – although in these places, tax reform was not necessarily implemented with the aim of reducing sprawl.

In principle, moving from a standard property tax to a land or split-rate tax has ambiguous effects on urban form. The capital to land ratio could rise through an increase in dwelling size – promoting sprawl – and/or through an increase in density or units per acre – promoting compact urban form (Brueckner and Kim, 2003). In practice, however, the density effect seems to dominate. Most of the empirical evidence supporting the role of property tax reform in promoting compact urban form comes from the U.S. state of Pennsylvania, where the most thorough study found that the split-rate tax led to a 4–5% point increase per decade in the number of housing units per hectare, with a minimal increase in unit size (for other evidence from Pennsylvania, see Oates and Schwab, 1997; Plassmann and Tideman, 2000; Banzhaf and Lavery, 2010).

Prospective or simulation studies also tend to find that land or split-rate taxes have the potential to promote compact urban form at least to some extent (many earlier studies are summarized in Roakes, 1996; Needham, 2000; for more recent work see Junge and Levinson, 2012). However, studies of land taxes in Australia have tended to find no effect on urban form (Skaburskis, 2003), although with some exceptions (e.g. Edwards, 1984; Lusht, 1992). There are several suggestions to tailor land or property taxes to explicitly support urban planning objectives. For example, the property tax could vary by use or by impervious area (Nuissl and Schroeter-Schlaack, 2009), or the tax could be on greenfield development only (Altes, 2009). However, there are few examples of these approaches in practice, and little or no empirical evidence of their impacts.

Moving from a standard property tax to a land or split-rate tax can yield efficiency and equity benefits (see Chapter 3 for definitions). The efficiency effect stems from the fact that the land tax is less distortionary than a tax on improvements, as the supply of land is fixed (Brueckner and Kim, 2003). The equity argument stems from the view that land value accrues because of the actions of the wider community, for example through infrastructure investments, rather than the actions of the landowner (Roakes, 1996). Indeed, some variants of the land tax in countries such as Colombia (Bird and Slack, 2007) take an explicit 'value capture' approach, and attempt to tax the incremental increase in land value resulting from transport projects.

Development impact fees are imposed per unit of new development to finance the marginal costs of new infrastructure required by the development, and are levied on a one-time basis. The effects of impact fees on urban form will be similar to a property tax. The main difference is that impact fees are more likely to be used by urban governments as a financing mechanism for transport infrastructure. For example, San Francisco and many British cities have impact fees dedicated to public transport (Enoch et al., 2005), and other cities such as Santiago have fees that are primarily dedicated to road infrastructure (Zegras, 2003).

Development taxes. To the extent that excessive urban development reflects the failure to charge developers for the full costs of infrastructure and the failure to account for the social benefits of spatially explicit amenities or open space, some economists argue that development taxes, a tax per unit of land converted to residential uses, are the most direct market-based instruments to correct for such failures (Brueckner, 2000; Bento et al., 2006). According to these studies, in contrast to urban growth boundaries, development taxes can control urban growth at lower economic costs. Urban sprawl occurs in part because the costs associated with development are not fully accounted for. Development taxes could make up for the difference between the private costs and the social costs of development, and coupled with urban growth boundaries could be effective at reducing sprawl.

Fuel prices and transportation costs. Increases in fuel taxes or transportation costs more generally have a direct effect on reducing VKT (see Chapter 8 and Chapter 15). They are also likely to have a long-run mitigation effect as households adjust their location choices to reduce travel distances, and urban form responds accordingly. An urban area that becomes more compact as households bid up the price of centrally located land is a core result from standard theoretical economic models of urban form (Romanos, 1978; Brueckner, 2001a, 2005; Bento et al., 2006).

Empirically, evidence for this relationship comes from cities in the United States, where a 10% increase in fuel prices leads to a 10% decrease in construction on the urban periphery (Molloy and Shan, 2013); Canada, where a 1% increase in gas prices is associated with a 0.32% increase in the population living in the inner city (Tanguay and Gingras, 2012); and cross-national datasets of 35 world cities (Glaeser et al., 2001; Glaeser and Kahn, 2004). However, another cross-national study using a larger dataset found no statistically significant link, which the authors attribute to noisiness in their (national-level) fuel price data (Angel et al., 2005).

Similar impacts on urban form would be expected from other pricing instruments that increase the cost of driving. While there is clear evidence that road and parking pricing schemes reduce emissions through direct impacts on mode and travel choices (see Chapter 8.10.1), there is more limited data on the indirect impacts through land-use patterns. One of the few simulation studies found that optimum congestion pricing would reduce the radius of the Paris metropolitan area by 34%, and the average travel distance by 15% (De Lara et al., 2013).

12.5.3 Integrated spatial planning and implementation

A characteristic of effective spatial planning is interlinked and coordinated efforts that are synergistic, and the sum of which are greater than each individual part incrementally or individually (Porter, 1997). Relying on a single instrument or one-size-fits-all approach can be ineffective or worse, have perverse, unintended consequences. Singapore is a textbook example of successfully bundling spatial planning and supportive pricing strategies that reinforce and strengthen the influences of each other (see Box 12.5). Bundling spatial strategies in ways that produce positive synergies often requires successful institutional coordination and political leadership from higher levels of government (Gakenheimer, 2011). The U.S. state of Oregon has managed to protect farmland and restrict urban sprawl through a combination of measures, including urban growth boundaries (required for all metropolitan areas above 50,000 inhabitants), farm tax credit programmes, tax abatements for infill development, and state grants that have helped fund investments in high-quality transit, such as light rail and tramways in Portland and BRT in Eugene (Moore et al., 2007). Enabling legislation introduced by the state prompted cities like Portland to aggressively curb sprawl through a combination of urban containment, targeted infrastructure investments, aggressive expansion of pedestrian and bikeway facilities, and commercial-rate pricing of parking (Nelson et al., 2004).

Box 12.5. Singapore: TOD and Road Pricing

The island-state of Singapore has over the years introduced a series of cross-cutting, reinforcing spatial planning and supportive strategies that promote sustainable urbanism and mobility (Suzuki et al., 2013). Guided by its visionary Constellation Plan, Singapore built a series of new master-planned towns that interact with each other because they each have different functional niches. Rather than being self-contained entities, these new towns function together (Cervero, 1998). All are interlinked by high-capacity, high-quality urban rail and bus services, and correspondingly the majority of trips between urban centres are by public transport. Congestion charges and quota controls on vehicle registrations through an auctioning system also explain why Singapore's transit services are so heavily patronized and not un-related, why new land development is occurring around rail stations (Lam and Toan, 2006).

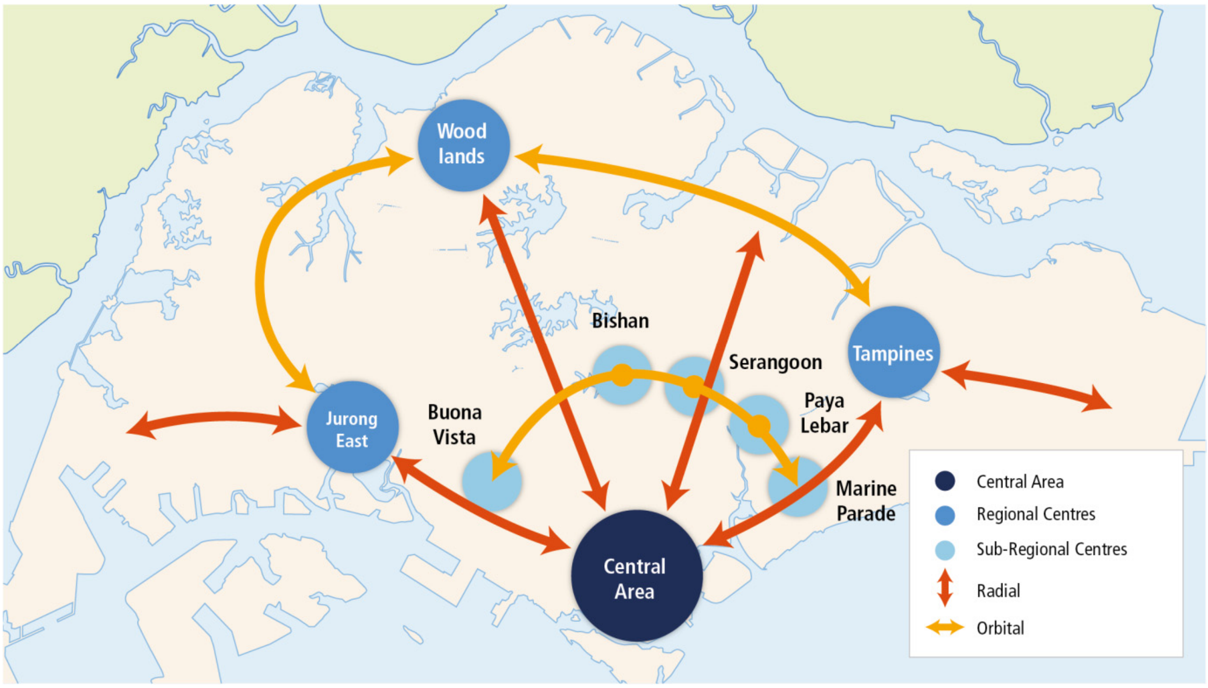


Figure 12.18. Singapore's Constellation Plan. Source: (Suzuki et al., 2013).

Empirical evidence on the environmental benefits of policies that bundle spatial planning and market strategies continues to accumulate. A 2006 experiment in Portland, Oregon, replaced gasoline taxes with VKT charges, levied on 183 households that volunteered for the experiment. Some motorists paid a flat VKT charge while others paid considerably higher rates during the peak than non-peak. The largest VKT reductions were recorded among households in compact, mixed-use neighbourhoods that paid congestion charges matched by little change in travel among those living in lower density areas and paying flat rates (Guo et al., 2011). Another study estimated that compact development combined with technological improvements (e.g., more efficient vehicle fleets and low-carbon fuels) could reduce GHG emissions by 15% to 20% (Hankey and Marshall, 2010). A general equilibrium model of urban regions in the OECD concluded that “urban density policies and congestion charges reduce the overall cost of meeting GHG emissions reduction targets more than economy-wide policies, such as a carbon tax, introduced by themselves” (OECD, 2010d).

12.6 Governance, Institutions, and Finance

The feasibility of spatial planning instruments for climate change mitigation depends greatly upon each city’s governance and financial capacities. Even if financial capacities are present, a number of other obstacles need to be surmounted. For example, many local governments are disinclined to support compact, mixed-use, and dense development. Even in cases where there is political support for low-carbon development, institutions may be ineffective in developing, implementing, or regulating land use plans. This section assesses the governance, institutional, and financial challenges and opportunities for implementing the mitigation strategies outlined in Section 12.5.

It needs to be emphasized that both the demand for energy and for urban infrastructure services, as well as the efficiency of service delivery, is also influenced by behaviour and individual choices. Cultural and lifestyle norms surrounding comfort, cleanliness, and convenience structure expectations and use of energy, water, waste, and other urban infrastructure services (Miller, 1998; Shove, 2003, 2004; Bulkeley, 2013). Individual and household choices and behaviour can also strongly affect the demand for, and the delivery efficiency of, public infrastructure services, for instance by lowering or increasing load factors (utilization rates) of public transport systems (Sammer, 2013). Governance and institutions are necessary for the design and implementation of effective policy frameworks that can translate theoretical emission reduction potentials of a range of mitigation options into actual improved emission outcomes.

12.6.1 Institutional and governance constraints and opportunities

The governance and institutional requirements most relevant to changing urban form and integrated infrastructure in urban areas relate to spatial planning. The nature of spatial planning varies significantly across countries, but in most national contexts, a framework for planning is provided by state and local governments. Within these frameworks, municipal authorities have varying degrees of autonomy and authority. Furthermore, there are often divisions between land use planning, where municipalities have the authority for land regulation within their jurisdiction, and transportation planning (which is either centrally organized or done in a cross-cutting manner), in which municipal responsibilities are often more limited. Thus, spatial planning is one area where municipalities have both the authority and the institutions to address GHG emissions.

However, the best plans for advancing sustainable urbanization and low-carbon development, especially in fast-growing parts of the world, will not become a reality unless there is both the political will and institutional capacity to implement them. The ability to manage and respond to escalating demands for urban services and infrastructure is often limited in developing country cities. Multiple institutional shortcomings exist, such as an insufficiently trained and undereducated civil service talent pool or the absence of a transparent and corruption-free procurement process for providing urban infrastructure (UN-Habitat, 2013). For example, limited experience with urban management, budgeting and accounting, urban planning, finance, and project supervision have thwarted Indonesia’s decentralization of infrastructure programmes from the central to local governments over the past decade (Cervero, 2013).

Although lack of coordination among local land management and infrastructure agencies is also a common problem in cities of industrialized countries (Kennedy et al., 2005), in developing cities institutional fragmentation undermines the ability to coordinate urban services within and across sectors (Dimitriou, 2011). Separating urban sector functions into different organizations – each with its own boards, staff, budgets, and by-laws – often translates into uni-sectoral actions and missed opportunities, such as the failure to site new housing projects near public transport stations. In addition, ineffective bureaucracies are notorious for introducing waste and delays in the deployment of urban transport projects.

In rapidly urbanizing cities, limited capacities and the need to respond to everyday crises often occupy most of the available time in transportation and public utility departments, with little attention left to strategically plan for prevention of such crises in the first place. As a result, strategic planning and coordination of land use and transportation across different transport modes is practically non-existent. Institutions rarely have sufficient time or funds to expand transport infrastructure fast enough to accommodate the exponential growth in travel. Public utilities for water and sanitation face similar challenges, and most local agencies operate constantly in the catch-up mode. Water utilities in southeast Asian cities, for example, are so preoccupied with fixing leaks, removing illegal connections, and meeting water purity standards that there is little time to strategically plan ahead for expanding trunk-line capacities in line with urban population growth projections. The ability to advance sustainable transport programmes, provide clean water connections, or introduce efficient pricing schemes implies the presence of conditions that rarely exist, namely a well-managed infrastructure authority that sets clear, measurable objectives and rigorously appraises the expenditure of funds in a transparent and accountable way (Cervero, 2013). Lack of local institutional capacity among developing cities is a major barrier to achieving the full potential that such cities have to reduce GHG emissions (UN-Habitat, 2013). This highlights the urban institutional climate conundrum that rapidly urbanizing cities—cities with the greatest potential to reduce future GHG emissions—are the cities where the current lack of institutional capacity will most obstruct mitigation efforts.

Curitiba, Brazil, regarded as one of the world's most sustainable cities, is a product of not only visionary spatial planning but also strong institutions and political leadership (see Box 12.6.). Other global cities are striving to follow Curitiba's lead. Bangkok recently announced a paradigm shift in planning that emphasizes redesigning the city to eliminate or shorten trips, create complete streets, and makes the city more liveable (Bangkok Metropolitan Administration, 2013). The Amman, Jordan, Master Plan of 2008 promotes high-density, mixed-use development through the identification of growth centres, intensification along select corridors across the city, and the provision of safe and efficient public transportation (Beauregard and Marpillero-Colomina, 2011). Similar transit-oriented master plans have been prepared for Islamabad, Delhi, Kuala Lumpur, and Johannesburg in recent years. Mexico City has aggressively invested in BRT and bicycle infrastructure to promote both a culture and built form conducive to sustainable mobility (Mejía-Dugand et al., 2013).

Box 12.6. Sustainable Curitiba: Visionary planning and strong institutions

Developing cities such as Curitiba, Brazil, well-known for advancing sustainable transport and urbanism, owe part of their success to strong governance and institutions (Cervero, 2013). Early in Curitiba's planning process, the Instituto de Pesquisa e Planejamento Urbano de Curitiba (IPPUC) was formed and given the responsibility of ensuring the integration of all elements of urban growth. Creative design elements, such as the trinary corridors (shown in Figure 12.19) that concentrate vertically mixed development along high-capacity dedicated busways and systematically taper densities away from transit corridors, were inventions of IPPUC's professional staff. As an independent planning and research agency with dedicated funding support, IPPUC is insulated from the whims of day-to-day politics and able to cost effectively coordinate urban expansion and infrastructure development. Sustained political commitment has been another important element of Curitiba's success. The harmonization of transport and urban development took place over 40 years, marked by a succession of progressive, forward-looking, like-minded mayors who built on the work of their predecessors. A cogent long-term vision and the presence of a politically insulated regional planning organization, IPPUC, to implement the vision have been crucial in allowing the city to chart a sustainable urban pathway.

However, urban governance of land use and transport planning is not the sole province of municipal authorities or 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 and guides for those who will occupy new or refurbished developments (e.g., age limits, types of home appliance that can be used, energy contracts, and education about how to reduce GHG emissions). Non-governmental organizations (NGOs) aimed at industry groups, such as the U.S. Green Building Council, the Korea Green Building Certification Criteria, and UK's Building Research Establishment Environmental Assessment Method (BREEAM) have also become important in shaping urban development, particularly in terms of regeneration and the refurbishment or retrofitting of existing buildings. For example, this is the case in terms of community-based organizations in informal settlements, as well as in the redevelopment of brownfield sites in Europe and North America.

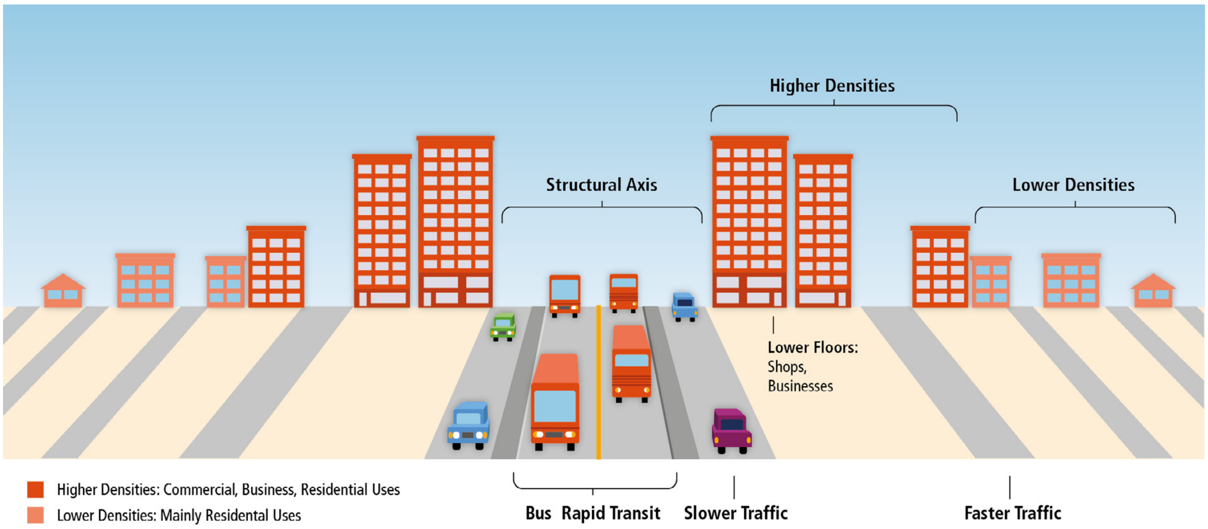


Figure 12.19. Curitiba's stylized trinary road system. The inclusion of mixed land uses and affordable housing allows developers to increase building heights, adding density to the corridor. Source: (Suzuki et al., 2013).

In addition to the internal institutional challenges outlined above, cities face the problem of coordinating policies across jurisdictional boundaries as their populations grow beyond the boundaries of their jurisdictions. Effective spatial planning and infrastructure provision requires an integrated metropolitan approach that transcends traditional municipal boundaries, especially to achieve regional accessibility. The fragmented local government structure of metropolitan areas facilitates the conversion of agricultural, forested, or otherwise undeveloped land to urban uses. These expanding urban areas also exhibit fiscal weaknesses, face heightened challenges of metropolitan transportation, and deficiencies in critical physical and social infrastructures (Rusk, 1995; Norris, 2001; Orfield, 2002; McCarney and Stren, 2008; Blanco et al., 2011; McCarney et al., 2011). Several efforts to address urban climate change mitigation at a metropolitan scale are emerging. The U.S. state of California, for example, is requiring metropolitan transportation agencies to develop climate change mitigation plans in concert with municipalities in their region. California's 2008 Sustainable Communities and Climate Protection Act, or SB 375, was the first legislation in the United States to link transportation and land use planning with climate change (State of California, 2008; Barbour and Deakin, 2012).

In order for integrated planning development to be successful, it must be supported at national levels (Gakenheimer, 2011). A recent example is India's National Urban Transport Policy of 2006, which embraces integrated transport and land use planning as its top priority. In this policy, the central government covers half the costs of preparing integrated transport and land use plans in Indian cities. Another example is that for the past 25 years, Brazil has had a national urban transport policy that supports planning for sustainable transport and urban growth in BRT-served cities like Curitiba and Belo Horizonte.

12.6.2 Financing urban mitigation

Urban infrastructure financing comes from a variety of sources, some of which may already be devoted to urban development. Some of these include 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 mitigation initiatives (OECD, 2010b), but access to these financial resources varies from one place to another.

In many industrialized countries, national and supra-national policies and programmes have provided cities with the additional financing and facilitations for urban climate change mitigation. Where the national commitment is lacking, state and municipal governments can influence mitigation initiatives at the city scale. Cities in emerging economies are also increasingly engaging in mitigation, but they often rely on international sources of funding. 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 liveability 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 through requirements to meet certain mitigation standards (OECD, 2010b). As decentralization has progressed worldwide (the average share of sub-national expenditure in OECD countries reached 33 % in 2005), regional and local governments increasingly manage significant resources.

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 by 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 U.S.

cities, a 20% reduction in single car trips in Ottawa, and a 38% increase of carpooling in Portland (OECD, 2010c).

Another way to think about the policy instruments available to governments for incentivizing GHG abatement is to consider each instrument's potential to generate public revenues or demand for government expenditures, and the administrative scale at which it can be applied (Figure 12.20). Here, the policy instruments discussed earlier (Table 12.5) are categorized into four groups: (1) regulation; (2) taxation/charge; (3) land-based policy; and (4) capital investment. Many of these are applicable to cities in both the developed and developing countries, but they vary in degree of implementation due to limited institutional or governance capacities. Overcoming the lack of political will, restricted technical capacities, and ineffective institutions for regulating or planning land use will be central to attaining low-carbon development at a city-scale.

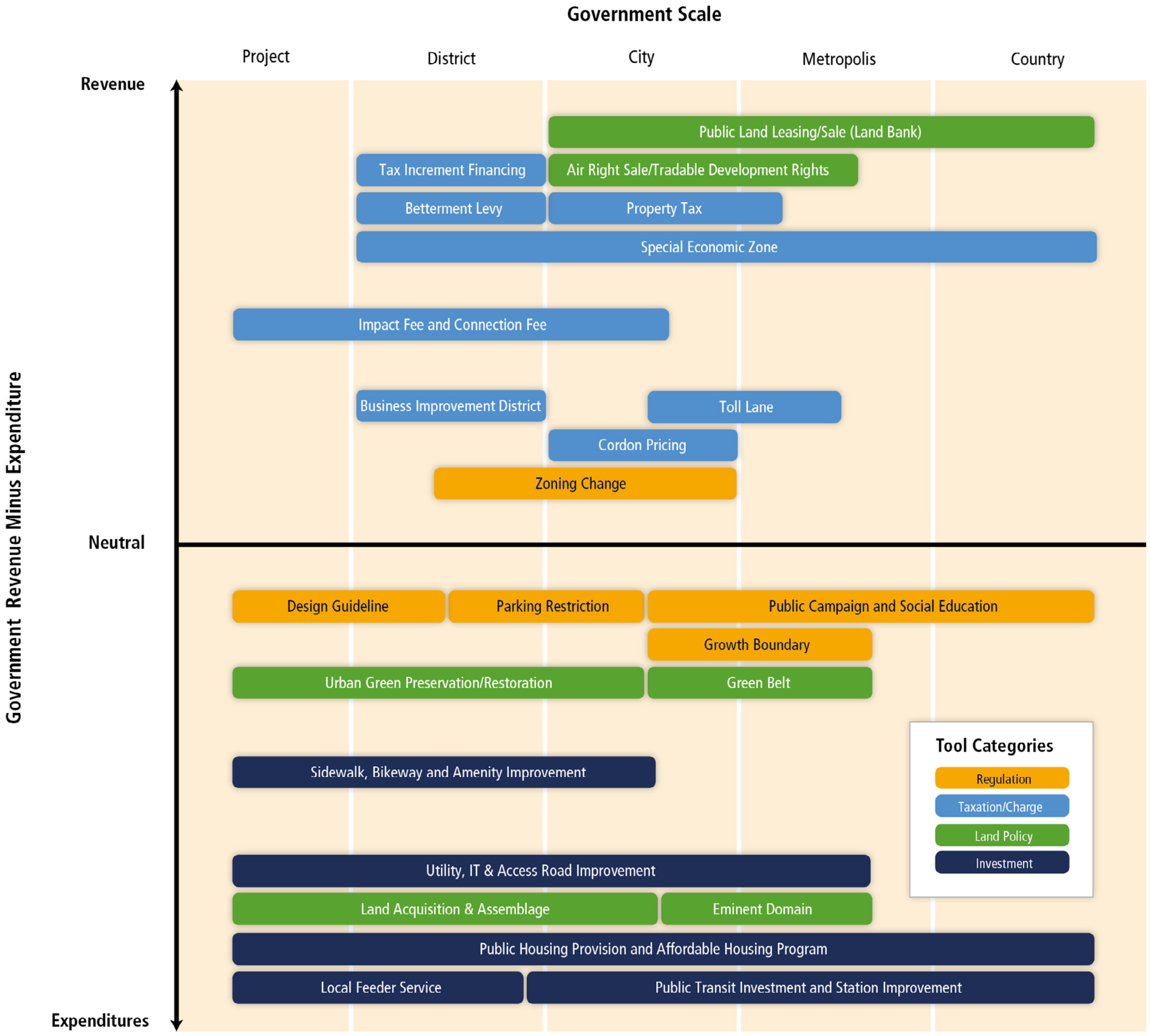


Figure 12.20. Key spatial planning tools and effects on government revenues and expenditures across administrative scales. Figure shows four key spatial planning tools (coded in colours) and the scale of governance at which they are administered (x-axis) as well as how much public revenue or expenditure the government generates by implementing each instrument (y-axis).

Sources: Bahl and Linn (1998); Bhatt (2011); Cervero (2004); Deng (2005); Fekade (2000); Rogers (1999); Hong and Needham (2007); Peterson (2009); Peyroux (2012); Sandroni (2010); Suzuki et al. (2013); Urban LandMark (2012); U.S. EPA (2013); Weitz (2003).

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 using the profits generated by the land value price increase associated with the presence of 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 based on 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 (Hagman and Misczynski, 1978; Callies, 1979).

The majority of the value capture for transit literature use U.S. cities as case studies in part because of the prevalence of low-density, automobile-centred development. However, there is an emerging literature on value capture financing that focus on developing country cities, which tend to be denser than those in OECD countries, and where there is more even shares of distinct travel modes (Cervero et al., 2004). Value capture typically is used for public transit projects. There are various ways to implement 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 programmes, joint developments and cost/benefit sharing, connection fees (Johnson and Hoel, 1985; Landis et al., 1991; Bahl and Linn, 1998; Enoch et al., 2005; Smith and Gihring, 2006). There is much evidence that public transit investments often increase land values around new and existing stations (Du and Mulley, 2006; Debrezion et al., 2007).

In summary, the following are key factors for successful urban climate governance: (1) institutional arrangements that facilitate the integration of mitigation with other high-priority urban agendas; (2) an enabling multilevel governance context that empowers cities to promote urban transformations; (3) spatial planning competencies and political will to support integrated land-use and transportation planning; and (4) sufficient financial flows and incentives to adequately support mitigation strategies.

12.7 Urban Climate Mitigation: Experiences and Opportunities

This section identifies the scale and range of mitigation actions being planned by municipal governments and assesses the evidence of successful implementation of the plans as well as barriers to further implementation. The majority of studies reviewed pertain to large cities in North America, Japan, and Europe, although there are some cross-city comparisons and case studies that include smaller cities in industrialized economies (Yalçın and Lefèvre, 2012; Dierwechter and Wessells, 2013) and cities in developing countries and emerging economies (Romero Lankao, 2007; Pitt, 2010).

Addressing climate change has become part of the policy landscape in many cities, and municipal authorities have begun to implement policies to reduce GHG emissions generated from within their administrative boundaries (Acuto, 2013; OECD, 2010a). The most visible way in which cities undertake mitigation is under the auspices of a climate action plan – a policy document created by a local government agency that sets out a programme of action to mitigate greenhouse gas emissions. Usually such plans include a GHG emissions inventory and an emissions reduction target, as well as a series of mitigation policies.

This section focuses on such climate action plans, as they provide the most comprehensive and consistent, albeit limited, evidence available regarding urban mitigation efforts. However, there is not a one-to-one correspondence between climate action plans and urban mitigation efforts. Even when included in climate action plans, mitigation measures may well have been implemented in the plan's absence, whether for climate-related or other reasons (Millard-Ball, 2012b). Conversely, climate action plans are only one framework under which cities plan for mitigation policies, and similar recommendations may also occur as part of a municipal sustainability, land-use, or transport plan (Bulkeley and Kern, 2006; GTZ, 2009; Bassett and Shandas, 2010). In these other types of plans, climate change may be one motivation, but mitigation measures are often pursued because of co-benefits such as local air quality (Betsill, 2001; Kousky and Schneider, 2003).

12.7.1 Scale of urban mitigation efforts

The number of cities that have signed up to voluntary frameworks 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). These voluntary frameworks provide technical assistance and political visibility. They include the C40 Cities Climate Leadership Group (C40), which by October 2013 counted most of the world's largest cities among its 58 affiliates (C40 Cities, 2013), the Cities for Climate Protection (CCP) Campaign, and the 2013 European Covenant of Mayors, which had over 5,200 members representing over 170 million people, or roughly one-third of the European population (The Covenant of Mayors, 2013). In the United States, nearly 1,100 municipalities, representing approximately 30% of the country's population, have joined the U.S. Conference of Mayors Climate Protection Agreement, thus committing to reduce their local GHG emissions to below 1990 levels (Krause, 2011a).

Such estimates represent a lower bound, as cities may complete a climate action plan or undertake mitigation outside one of these voluntary frameworks. In California in 2009, 72% of cities responding to a survey stated they had adopted policies and/or programmes to address climate change, but only 14% had adopted a GHG reduction target (Wang, 2013). In some countries, climate action plans are mandatory for local governments, further adding to the total. 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 France, climate action plans are mandatory for cities with populations larger than 50,000 (Yalçın and Lefèvre, 2012). Climate action planning has been most extensive in cities in Annex I countries, particularly those in Europe and Japan. This presents a mismatch between the places with mitigation planning efforts, and the places where most urban growth will occur—and where the greatest mitigation potential exists—largely in developing countries that are rapidly urbanizing.

Box 12.7. Urban climate change mitigation in less developed countries

The majority of future population growth and demand for new infrastructure will take place in urban areas in developing countries. Africa and Asia will absorb the bulk of the urban population growth, and urbanization will occur at lower levels of economic development than the urban transitions that occurred in Annex I countries. There are currently multiple urban transitions taking place in developing countries, with differences in part due to their development histories, and with different impacts on energy use and greenhouse gas emissions.

Urban areas in developing and least developed countries can have dual energy systems (Martinot et al., 2002; Berndes et al., 2003). That is, one segment of the population may have access to modern energy and associated technology for heating and cooking. Another segment of the population—mainly those living in informal settlements—may rely mainly on wood-based biomass. Such non-commercial biomass is a prominent source in the urban fuel mix in Sub-Saharan Africa (50%) and in South Asia (23%). In other regions, Latin America and the Caribbean (12%), Pacific Asia (8%) and China (7%) traditional, non-commercial energy is not negligible but a relatively smaller proportion of overall energy portfolio (Grubler et al., 2012). The traditional energy system operates informally and inefficiently, using out-dated technology. It can be associated with significant health impacts (see Chapters 2 and 9 in IPCC, 2011). The unsustainable harvesting of woodfuels to supply large urban and industrial markets is significantly contributing to forest degradation and coupled with other land-use changes to deforestation (see Chapter 11). However, recent technological advances suggest that energy production from biomass can be an opportunity for low carbon development (Zeng et al., 2007; Fargione et al., 2008; Hoekman, 2009; Azar et al., 2010). Projections of significant growth in woodfuel demand (Mwampamba, 2007; Zulu, 2010; Agyeman et al., 2012) make it vital that this sector is overhauled and modernized using new technologies, approaches, and governance mechanisms.

Additionally, informal urbanization may not result in an increase in the provision of infrastructure services. Rather, unequal access to infrastructure, especially housing and electricity, is a significant problem in many rapidly growing urban centres in developing countries and shapes patterns of urban development. Mitigation options vary by development levels and urbanization trajectories. The rapid urbanization and motorization occurring in many developing and least developed countries is constrained by limited infrastructure and deteriorating transport systems. Integrated infrastructure development in these areas can have greater effects on travel demands and low-emission modal choices than in high-income countries, where infrastructure is largely set in place (see Chapter 8.9). The scale of new building construction in developing countries follows a similar path. An estimated 3 billion people worldwide rely on highly polluting and unhealthy traditional solid fuels for household cooking and heating (Pachauri et al., 2012; International Energy Agency, 2012)and shifting their energy sources to electricity and clean fuels could strongly influence building-related emissions reductions (see Box 9.1 and Section 14.3.2.1). Thus, it is in developing and least developed country cities where opportunities for integrated infrastructure and land-use planning may be most effective at shaping development and emissions trajectories, but where a ‘governance paradox’ exists (see Section 12.3.1).

12.7.2 Targets and timetables

One way to assess the scale of planned mitigation is through the emission reduction targets set by cities, typically as part of their climate action plans. A central feature of municipal climate change responses is that targets and timetables have frequently exceeded national and international ambitions for emissions reduction. 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 and the average city reduction target of 1.44% per year exceeds the national target (Sippel, 2011). In the United States, 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 United States (Krause, 2011b). Lutsey and Sperling (2008) find that these and other targets in 684 U.S. cities would reduce total emissions in the United States by 7% below the 2020 business-as-usual (BAU) baseline.

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 approach has not been limited to cities in developed economies. For example, the city of Cape Town has set a target of increasing energy efficiency within the municipality by 12% by 2010 (Holgate, 2007), and Mexico City has implemented a target of reducing GHG by 12% below 1990 levels by 2012 (Romero Lankao, 2007). Data compiled for this assessment, although illustrative rather than systematic, indicate an average reduction of 2.74 t CO_2eq/cap if cities were to achieve their targets, with percentage targets ranging from 10% to 100%. In general, percentage reduction targets are larger for more distant years and in more affluent cities. However, the absolute level of the targeted reductions depends primarily on the city's population and other determinants of baseline emissions (Figure 12.21.).

In some cases, targets may reflect patterns of potential mitigation. Targets are often arbitrary or aspirational, and reflect neither mitigation potential nor implementation. How targets translate into mitigation effort also depends on how they are quantified, e.g., whether fuel economy and similar improvements mandated at the national level are claimed by cities as part of their own reductions (Boswell et al., 2010; DeShazo and Matute, 2012). Mitigation targets are often set in absolute terms, which may be less meaningful than per-capita reductions in assessing mitigation potential at the metropolitan scale. This is a particularly important issue for central cities and inner suburbs, where population and emissions may increase within the city boundary if policies to increase density and compactness are successful (see Section 12.4; Ganson, 2008; Salon et al., 2010).

Many cities, particularly those in developing countries, do not set targets at all. 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—2008 (Government of NCT of Delhi, 2010), while the contributions from 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 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.

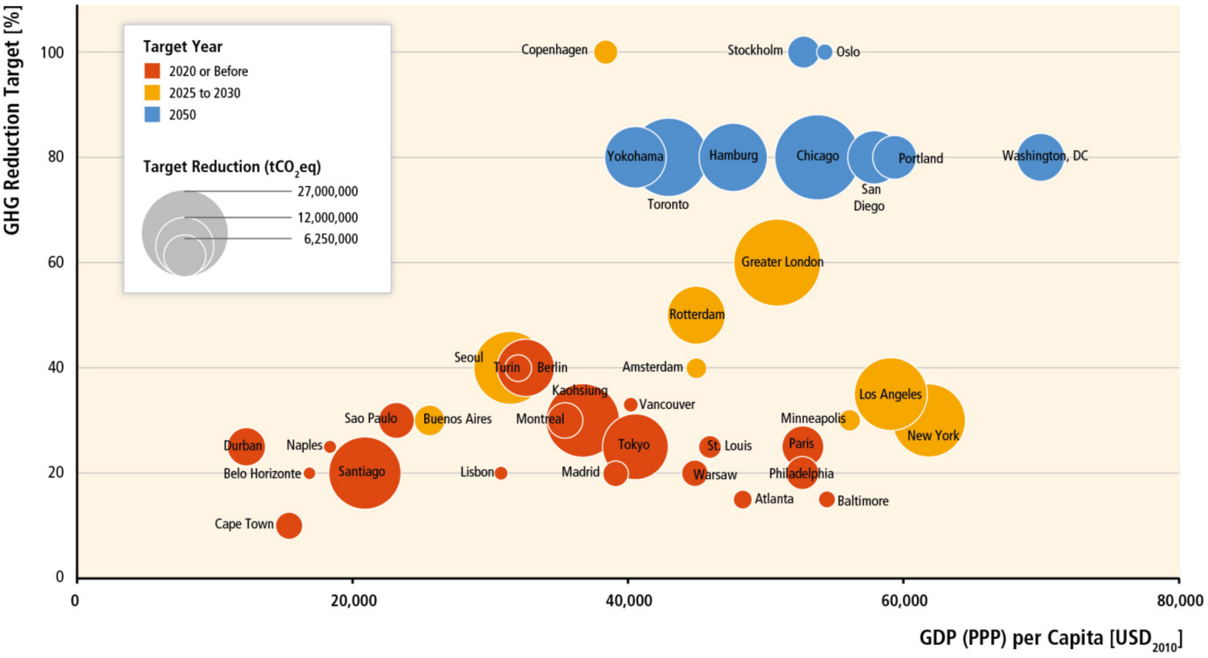


Figure 12.21. Mitigation targets for 42 cities. Sources: Baseline emissions, reduction targets, and population from self-reported data submitted to Carbon Disclosure Project (2013). GDP data from Istrate & Nadeau (2012). Note that the figure is illustrative only; data are not representative, and physical boundaries, emissions accounting methods and baseline years vary between cities. Many cities have targets for intermediate years (not shown).

12.7.3 Planned and implemented mitigation measures

Limited information is available on the extent to which targets are being achieved or emissions reduced. Some cities have already achieved their initial GHG reduction targets, e.g., Seattle (Boswell et al., 2011), or are on track to do so, e.g., Stockholm (City of Stockholm, 2013). In other places such as western Germany, few if any cities are likely to meet their targets (Sippel, 2011). Further data come from comparison of 'before' and 'after' GHG inventories. One study of six major cities found that emissions are falling by an average 0.27 t CO2eq/cap per year (Kennedy et al., 2012). Overall, however, the available data are usually incomplete, self-reported, and subject to various biases. More fundamentally, changes in aggregate emissions do not necessarily reflect the success or failure to implement mitigation measures, because so many drivers of emissions – including the electricity generation mix and fuel taxation – are normally beyond the control of cities (DeShazo and Matute, 2012). Whether a city achieves its target has less to do with its own actions and more to do with external drivers of emissions.

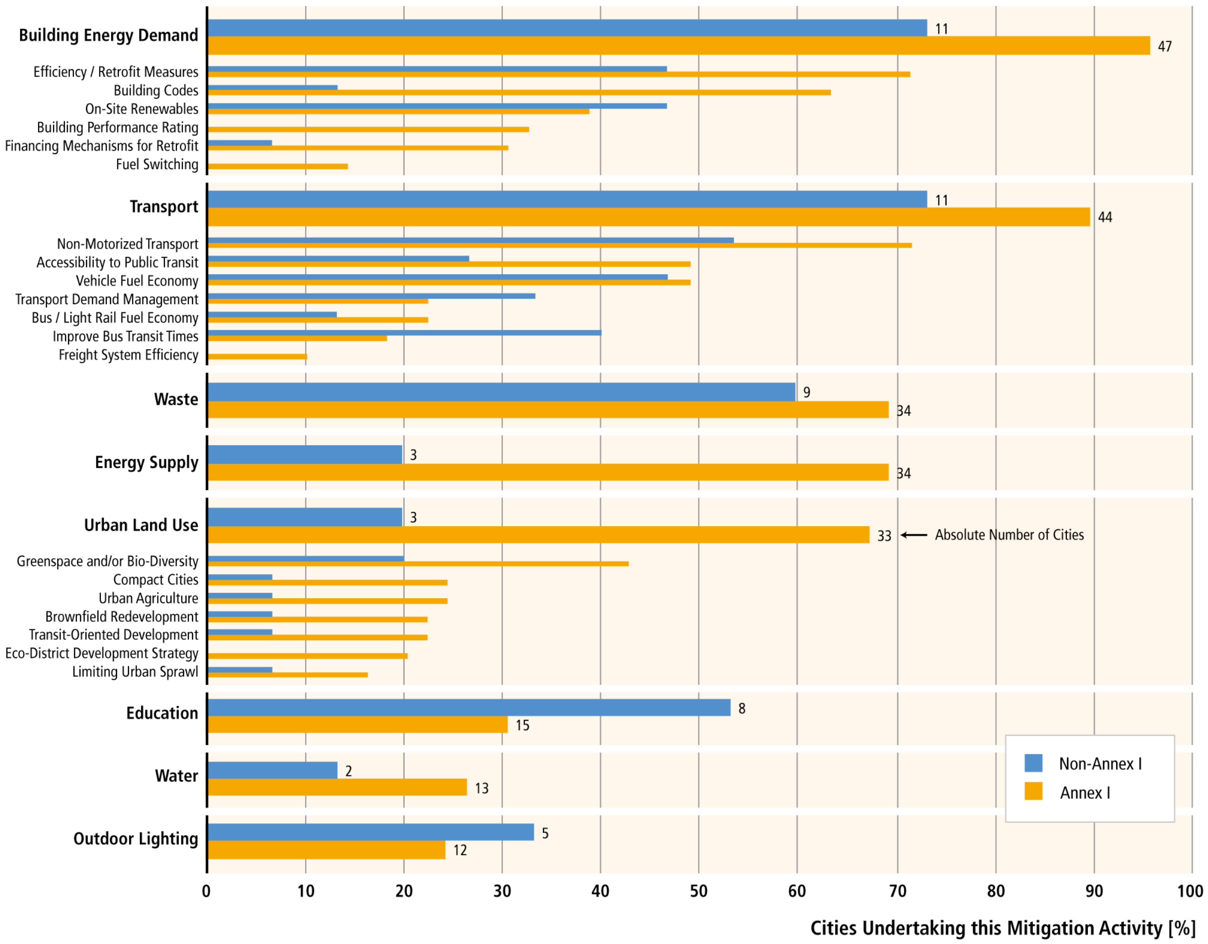


Figure 12.22. Mitigation measures in climate action plans. Sources: Compiled for this assessment from self-reported data submitted to Carbon Disclosure Project (2013).

An alternative way to gauge the extent of planned and implemented mitigation measures is through a bottom-up analysis of individual policies (Ramaswami et al., 2012a) or sector-specific data on green buildings, transport, or waste production (Millard-Ball, 2012a). However, there are no data from a large number of cities using these methods. Instead, available data are usually in the form of self-reported planned or implemented policies (Krause, 2011c; Castán Broto and Bulkeley, 2012; Stone et al., 2012; Bedsworth and Hanak, 2013). While these data do not reveal aggregate emission reductions, they indicate the sectoral breadth of city climate action plans and the types of measures that cities are planning. No single sector dominates mitigation plans, although transportation and building efficiency are the most common self-reported measures (Figure 12.22). Here it is worth noting that the relative contribution of sectors to total urban emissions varies greatly by city (see Section 12.3).

The types of land-use strategies discussed in Section 12.5, such as compact development, are sometimes included in municipal efforts or plans, but the popularity of such land-use measures varies considerably by context. In California, 80% of municipal survey respondents reported that they had policies for high-density or mixed-use development in place or under consideration, and the adoption of such land-use policies rose substantially between 2008 and 2010 (Bedsworth and Hanak, 2013). In the United States, 70% of climate action plans reviewed in one study include compact development strategies (Bassett and Shandas, 2010). In contrast, municipal climate plans in Norway and Germany focus on energy, transport and building efficiency, with little attention given to land use (Aall et al., 2007; Sippel, 2011). At a global level, self-reported data from a small sample of cities (Figure 12.22) suggests that land-use measures are relatively uncommon in climate action plans – particularly outside Annex I countries. Moreover, where land-use strategies exist, they focus on urban greenspace and/or biodiversity, rather than on the cross-sectoral measures to reduce sprawl and promote TOD that were discussed in Section 12.5.

Even if land use measures are listed in climate action plans, implementation has focused on win-win energy efficiency measures that lead to cost savings, rather than larger changes to land use, buildings or transport. This is a consistent message from qualitative studies (Kousky and Schneider, 2003; Rutland and Aylett, 2008; Kern and Bulkeley, 2009), and some larger surveys of city efforts (Wang, 2013). There has been less engagement by municipalities with sectors such as energy and water supply that often lie outside of their jurisdiction (Bulkeley and Kern, 2006; ARUP, 2011) or with the GHG emissions embodied in present patterns of urban resource use and consumption. More broadly, there is considerable variation in the nature and quality of climate change plans, particularly when it comes to specifying the detail of actions and approaches to implementation (Wheeler, 2008; Tang et al., 2011; Bulkeley and Schroeder, 2012).

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 mitigation projects, the impacts of these initiatives are not often evaluated (see Chapter 15 on policy evaluation). Cities' mitigation reduction performance is largely correlated to the national performance in mitigation reduction.

12.8 Sustainable Development, Co-Benefits, Trade-offs, and Spill-over Effects

Sustainable development (SD) is, and has always been, closely associated with human settlements. In fact, the very document that coined the phrase, the World Commission on Environment and Development (WCED) Report (WCED 1987), devoted a chapter to 'the urban challenge'. While averting the adverse social and environmental effects of climate change remains at the core of the urban challenge today, cities throughout the world also continue to struggle with a host of other critical challenges, including, for instance, ensuring access to clean, reliable and affordable energy services for their citizens (particularly for the urban poor); limiting congestion, noise, air and water pollution, and health and ecosystem damages; and maintaining sufficient employment opportunities and competitiveness in an increasingly globalized world.

Efforts to mitigate climate change will have important side-effects for these various policy objectives, as discussed in Sections 5.7, 6.6, 7.9, 8.7, 9.7, 10.8, 11.7 and 11.A.6. To the extent these side-effects are positive, they can be deemed 'co-benefits'; if adverse, they imply 'risks'.[3] As such side-effects are likely to materialize first in urban settings since these are the hubs of activity, commerce, and culture in the modern world: this section will focus on the literature specifically linked to urban settings and refer to other sections of the report where appropriate.

Action on climate change mitigation often depends on the ability to 'reframe' or 'localize' climate change with respect to the co-benefits that could be realized (Betsill, 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 et al., 2009). Sometimes called 'localizing' or 'issue bundling' (Koehn, 2008), these reframing strategies have proven to be successful in marshalling local support

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[3] Co-benefits and adverse side-effects describe co-effects without yet evaluating the net effect on overall social welfare. Please refer to the respective sections in the framing chapters as well as to the glossary in Annex I for concepts and definitions – particularly Sections 2.4, 3.6.3, and 4.8.2.

and action in developing country cities, and will continue to be an important component of developing local capacity for mitigation (Puppim de Oliveira, 2009).

Table 12.6. Potential co-benefits (green arrows) and adverse side-effects (orange arrows) of urban mitigation measures. Arrows pointing up/down denote a positive/negative effect on the respective objective or concern. The effects depend on local circumstances and specific implementation strategy. For an assessment of macroeconomic, cross-sectoral effects associated with mitigation policies (e.g., on energy prices, consumption, growth, and trade), see Sections 3.9, 6.3.6, 13.2.2.3 and 14.4.2.

Mitigation measures	**Effect on additional objectives/concerns**		
	Economic	**Social (including health)**	**Environmental**
Compact development and infrastructure	↑ Innovation and productivity[1] ↑↑ Higher rents & residential property values[2] ↑ Efficient resource use and delivery[5]	↑ Health from physical activity[3]	↑ Preservation of open space[4]
Increased accessibility	↑ Commute savings[6]	↑ Health from increased physical activity[3] ↑ Social interaction & mental health[7]	↑ Air quality and reduced ecosystem/health impacts[8]
Mixed land use	↑ Commute savings[6] ↑↑ Higher rents & residential property values[2]	↑ Health from increased physical activity[3] ↑ Social interaction and mental health[7]	↑ Air quality and reduced ecosystem/health impacts[8]

Sources: 1 (Ciccone and Hall, 1996; Carlino et al., 2007) ;2 (Mayer and Somerville, 2000; Quigley and Raphael, 2005; Glaeser et al., 2006; Koster and Rouwendal, 2012) ; 3 (Handy et al., 2002; Frank et al., 2004, 2009; Heath et al., 2006; Forsyth et al., 2007; Owen et al., 2007); 4 (Brueckner, 2000; Bengston et al., 2004); 5 (Speir and Stephenson, 2002; Guhathakurta and Gober, 2007) 6 (Krizek, 2003; Cervero and Duncan, 2006; Ma and Banister, 2006; Day and Cervero, 2010); 7 (Galea et al., 2005; Berke et al., 2007; Duncan et al., 2013); 8 (Campbell-Lendrum and Corvalán, 2007; Creutzig and He, 2009; Milner et al., 2012; Puppim de Oliveira et al., 2013).

12.8.1 Urban air quality co-benefits

Worldwide, only 160 million people live in cities with truly clean air – that is, in compliance with World Health Organization (WHO) guidelines (Grubler et al., 2012) (Figure 12.23). Oxides of sulfur and nitrogen (SO_x and NO_x) and ozone (O_3)—i.e., outdoor air pollutants—are particularly problematic in cities because of high concentrations and exposures (Smith et al., 2012) (see Section 9.7 for a discussion of mitigation measures in the buildings sector on indoor air pollution and Section 7.9.2). Transport remains one of the biggest emitting sectors in the industrialized world. In developing countries, a wider range of sources is to blame, with vehicle emissions playing an ever increasing role also due to continuing urbanization trends (Kinney et al., 2011; Smith et al., 2012) (see also Sections 5.3.5.1 and 8.2). In a study of four Indian megacities, for instance, gasoline and diesel vehicle emissions already comprise 20–50% of fine particulate matter ($PM_{2.5}$) emissions (Chowdhury et al., 2007). The associated health burdens are particularly high in low-income communities due to high exposures and vulnerabilities (Campbell-Lendrum and Corvalán, 2007; Morello-Frosch et al., 2011).

Major air quality co-benefits can be achieved through mitigation actions in the urban context, especially in megacities in developing countries where outdoor air pollution tends to be higher than in urban centres in industrialized countries (Molina and Molina, 2004 and section 5.7). Urban planning strategies and other policies that promote cleaner fuels, transport mode shifting, energy cogeneration and waste heat recycling, buildings, transport and industry efficiency standards can all contribute to lower rates of respiratory and cardiovascular disease (improved human health) as well as decreased impacts on urban vegetation (enhanced ecosystems) via simultaneous reductions in co-emitted air pollutant species (Campbell-Lendrum and Corvalán, 2007; Creutzig and He, 2009; Milner et al., 2012; Puppim de Oliveira et al., 2013 and sections 7.9, 8.7, 9.7, 10.88 as well as WGII chapter

11.9).[4] Even an action like shading parking lots, which is generally thought of in the context of limiting the urban heat-island effect, can bring air pollution co-benefits through reductions in volatile organic compounds (VOC) and, thus, low-level ozone formation from parked vehicles (Scott et al., 1999).

In the near-term (2030), air quality co-benefits of stringent mitigation actions (i.e., in line with achieving 450 ppm CO_2eq by 2100) can be quite substantial in a highly urbanized region like Europe; decarbonization and energy efficiency (largely in transport) could reduce aggregate NO_x emissions by a further 38% relative to a baseline scenario that includes current and planned air quality legislation by 2030 but does not consider climate policies (Colette et al., 2012). Similar co-benefits have been reported for other pollutants in other regions (Rao et al., 2013), particularly in developing Asia (Doll and Balaban 2013; Geng, Ma et al. 2013; Puppim de Oliveira, Doll et al. 2013) (see Section 6.6). The potential for realizing these co-benefits depends on institutional frameworks and policy agendas at both the local and national level, as well as the interplay between the two (see Doll, Dreyfus et al. (2013) and Jiang et al. (2013) for reviews of India and China). At the same time, the increasing role of decentralized power generation could lead to adverse air quality side-effects if this trend is not coupled with a more intensive use of low-carbon energy supply (Milner et al., 2012).

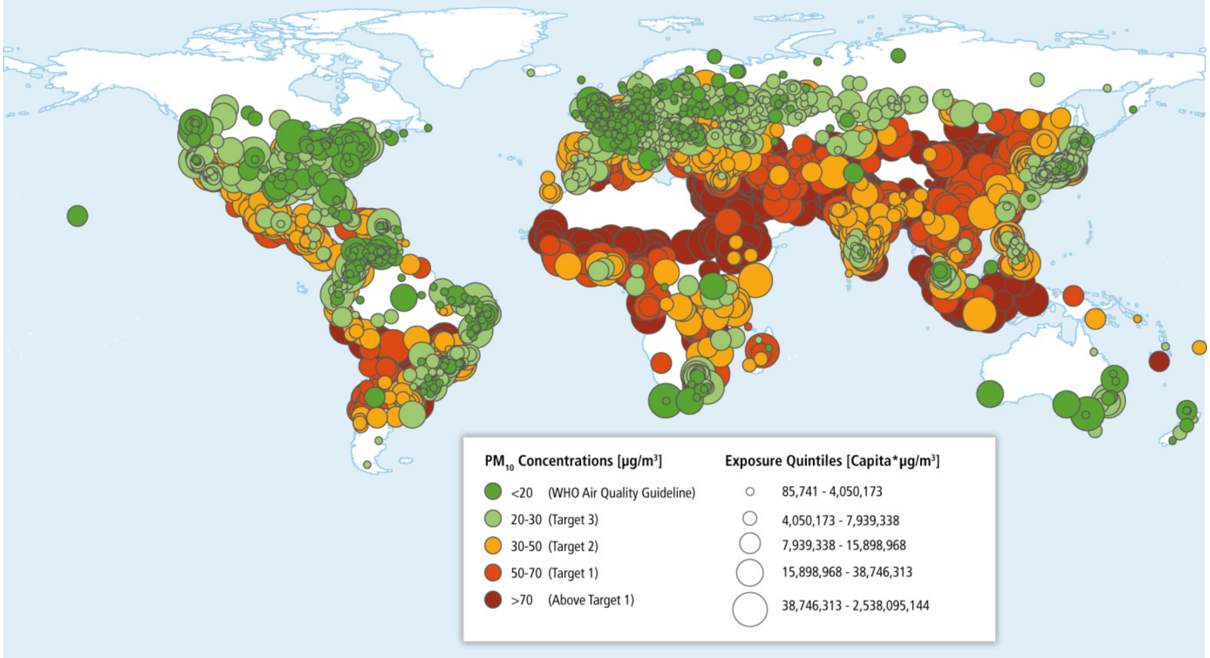

Figure 12.23. Human risk exposure to PM_{10} pollution in 3200 cities worldwide. Sources: (Doll, 2009; Doll and Pachauri, 2010; Grubler et al., 2012).

12.8.2 Energy security side-effects for urban energy systems

Mitigating climate change could have important side-effects for urban energy security (sufficient resources and resilient supply) – concerns that have re-emerged in many cities throughout the world in recent years (see Sections 6.6.2.1 and 7.9.1 for a broader discussion of energy security concerns). Perhaps the greatest energy-related vulnerability in this context is the fact that urban transport systems are at present almost entirely dependent on oil (Cherp et al., 2012). This is especially true in low-density areas where reliance on private vehicles is high (Levinson and Kumar 1997). Therefore, any mitigation activities leading to a diversification of the transport sector away from oil could potentially also contribute to a security co-benefit (see (Jewell et al., 2013) and other references in

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[4] Monetized health co-benefits are found to be larger in developing countries than industrialized countries, a finding that results from the currently higher pollution levels of the former and, thus, the greater potential for improving health, particularly in the transport and household energy demand sectors (Markandya et al., 2009; Nemet et al., 2010; West et al., 2013 and Section 5.7).

Chapter 8.7.1). Such measures might range from technology standards (e.g., for vehicles and their fuels) to integrated infrastructure, spatial planning, and mass transit policies (Sections 12.5 and 8.10). Energy efficiency regulations for buildings and industrial facilities (both existing and new) can also help to enhance the resilience of fuel and electricity distribution networks (see Chapters 9.7 and 10.8).

12.8.3 Health and socioeconomic co-benefits

Spatial planning and TOD can yield other positive side-effects that may enhance a city's liveability. For example, mass transit requires considerably less physical space than private automobiles (transit: 0.75–2.5 m^2/cap; auto: 21–28 m^2/cap) and generally emits less noise (Grubler, Bai et al. 2012), with health co-benefits in terms of cardiovascular disease and sleep disturbance (Kawada, 2011; Ndrepepa and Twardella, 2011 see also 8.7; Milner et al., 2012).

Neighbourhoods with walkable characterististics such as connectivity and proximity of destinations are correlated with higher frequency of physical activity among residents (Frank et al., 2004; Owen et al., 2007), which is correlated with lower symptoms and incidences of depression (Galea et al., 2005; Berke et al., 2007; Duncan et al., 2013). Compact neighbourhoods with more diversified land uses are correlated with higher housing prices and rents (Mayer and Somerville, 2000; Quigley and Raphael, 2005; Glaeser et al., 2006; Koster and Rouwendal, 2012). In a study of the Netherlands, neighbourhoods with more diverse land uses had a 2.5% higher housing prices (Koster and Rouwendal, 2012).

12.8.4 Co-benefits of reducing the urban heat island effect

The urban heat island (UHI) effect presents a major challenge to urban sustainability (see WGII Chapter 8). Not only does UHI increase the use of energy for cooling buildings (and thus increasing the mitigation challenge) and thermal discomfort in urban areas, but UHI also increases smoggy days in urban areas, with smog health effects present above 32°C (Akbari et al., 2001; O'Neill and Ebi, 2009; Mavrogianni et al., 2011; Rydin et al., 2012). 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, 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). 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 CO_2 emissions annually (Akbari et al., 2008).

Reducing summer heat in urban areas has several co-benefits. Electricity use in cities increases 2–4% for each 1°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 GHG 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 global mean surface 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 (Mickley et al., 2004; Jacob and Winner, 2009). In addition, it is likely that cities will experience an increase in UHI as a result of projected increases in global mean surface 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 for 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, which is increasing densities to create more compact cities (Milner et al., 2012). This conflict illustrates the complexity of developing integrated and effective climate change policies for urban areas.

More generally, reducing UHI effects—either through mitigation measures (e.g., improved waste heat recycling, co-generation, use of reflective building materials, increased vegetation) or through mitigation—can have co-benefits for urban water supplies (e.g., cooling water for thermal or industrial plants, drinking water), given that evaporation losses rise as water bodies warm (Grubler et al., 2012).

12.9 Gaps in Knowledge and Data

This assessment highlights a number of key knowledge gaps:

- **Lack of 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 urban share of global GHG emissions as well as develop urbanization and typologies and their emission pathways. Given the small number of city based estimates, more city data and research are needed, especially an urban emissions data system.
- **Little scientific understanding of the magnitude of the emissions reduction from altering urban form, and the emissions savings from integrated infrastructure and land use planning.** Furthermore, there is little understanding of how different aspects of urban form interact and affect emissions. The existing research on the impact of policies designed to achieve emissions reductions through urban form do not conform to the standards of policy evaluation and assessment defined in Chapter 15.
- **Lack of consistency and thus comparability 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.
- **Few evaluations of 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 (Stone et al., 2012; Millard-Ball, 2012a). 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).
- **Lack of scientific understanding of 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, while other will be in the 'red zone' for their high levels of emissions. Local decision-makers need clarity on where to focus their actions, and to avoid spending resources and efforts on policies and investments that 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. Policy packages will be determined based on the characteristics of individual cities and their urbanization and development pathways, as well as on forecasts 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.

- **Large uncertainties as to how cities will develop in the future.** There is robust scientific evidence that emissions vary across cities and that urban form and infrastructure play large roles in determining the relationship between urbanization and emissions.

12.10 Frequently Asked Questions

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?

Urbanization is a global megatrend that is transforming societies. Today, more than 50% of the world population lives in urban areas. By 2050, the global urban population is expected to increase by between 2.5 to 3 billion, corresponding to 64% to 69% of the world population. By mid-century, more urban areas and infrastructure will be built than currently exist. The kinds of towns, cities, and urban agglomerations that ultimately emerge over the coming decades will have a critical impact on energy use and carbon emissions. The Fourth Assessment Report (AR4) of the IPCC did not have a chapter on human settlements or urban areas. Urban areas were addressed through the lens of individual sector chapters. Since the publication of AR4, there has been a growing recognition of the significant contribution of urban areas to GHG emissions, their potential role in mitigating them, and a multi-fold increase in the corresponding scientific literature.

FAQ 12.2 What is the urban share of global energy and GHG emissions?

The exact share of urban energy and GHG emissions varies with emission accounting frameworks and definitions. Urban areas account for 67–76% of global energy use and 71–76% of global energy-related CO_2 emissions. Using Scope1 accounting, urban share of global CO_2 emissions is about 44%. Urban areas account for between 53% and 87% (central estimate, 76%) of CO_2 emissions from global final energy use and between 30% and 56% (central estimate, 43%) of global primary energy related CO_2 emissions.

FAQ 12.3: What is the potential of human settlements to mitigate climate change?

Drivers of urban GHG emissions can be categorized into four major groups: economic geography and income, socio-demographic factors, technology, and infrastructure and urban form. Of these, the first three groups have been examined in greatest detail, and income is consistently shown to exert a high influence on urban GHG emissions. Socio-demographic drivers are of medium importance in rapidly growing cities, technology is a driver of high importance, and infrastructure and urban form are of medium to high importance as drivers of emissions. Key urban form drivers of GHG emissions are density, land use mix, connectivity, and accessibility. These factors are interrelated and interdependent. As such, none of them in isolation are sufficient for lower emissions.

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