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Author(s):	CLAs:	Shobhakar Dhakal and Karen C. Seto		
	LAs:	Anthony Bigio, Hilda Blanco, Gian Carlo Delgado, David Dewar, Luxin Huang, Shu-Li Huang, Atsushi Inaba, Arun Kansal, Shuaib Lwasa, James McMahon, Daniel Mueller, Harini Nagendra, Cecilia Tacoli		
	CA:	Felix Creutzig		
Support:	CSA:	Peter Christensen		
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Chapter 12: Human Settlements, Infrastructure and Spatial Planning

Contents

Executive Summary

In the process of development of human settlements, urbanization is the dominant trend in last several decades and will continue to be so. There are several drivers in this process such as demographic, social, economic, trade and institutions. Urban areas generate more than 90% of global economy (*high agreement, much evidence*).

Urban settlements contribute significantly to the total GHG emissions. Urban areas account for about 70% energy related total CO2 emissions based on production side allocation of CO2 emissions including emissions during electricity generation that are consumed in cities. If CO2 emissions are allocated to consumption side of goods and service then urban areas' contribution is expected to be higher. Estimates of urban contributions to GHG emission vary due to variations in the definition of urban by country and study, and different emission allocation principles. When normalized by urban population, per capita emissions of urban areas are almost always lower than national averages in developed countries while there are indications for the opposite relation in developing countries due to factors such as income and energy mix structure (*high agreement, much evidence*). There is no consensus on the best approach to account for urban GHG emissions and there is a need for standardized methodologies for city-level carbon accounting.

Settlement structure and form influence mitigation opportunities through population and employment density, tendencies towards linearity, land use mix, connectivity, building form and height, carbon sinks and intermixing of scale and urban fabric at multiple scale within settlements. A combination of compact urban form, integrated urban structure, high residential and employment density, and mixed land uses, provides a coherent urban model that can lower energy use and carbon emissions (*high agreement, medium evidence*). There are opportunities, by means of urban form and mixed land uses, for new and growing cities to reduce the negative effects of infrastructure lock-in (*high agreement, medium evidence*). There are different challenges and opportunities for mitigation in developed countries, emerging economies and less developing countries, as well as for expanding cities, shrinking cities, and stable cities.

Human settlements are complex open systems with linkages to hinterlands across multiple scales. Consequently, human settlements can directly lowering emissions from activities within their administrative boundaries as well as indirectly through material and resource use. As a system, urban areas and human settlements can increase the efficiency of the built environment, infrastructure and energy use beyond what is possible within individual sectors (*high agreement, medium evidence*).

Spatial planning can influence resource use and emissions through spatial development plans, land use, building regulations, and the coordination of infrastructure, services, and land use (*high agreement, much evidence*). The spatial organization of human settlements and their built environments are major factors that determine energy use and emissions through the layout of streets and buildings, accessibility to jobs and markets, infrastructure investments, and transportation corridors (*high agreement, much evidence*). Once in place, the basic spatial structures of human settlements are difficult to change. The form and structure of human settlements, especially cities, facilitates or hinders transport choices, housing options, building types, and ultimately lifestyles. While spatial planning can influence energy use and emissions, there are limited quantitative assessments of the emissions savings through spatial planning strategies (*high agreement, low evidence*).

Governance of mitigation in settlements benefits from a poly-centric and multilevel governance approach (*medium agreement, medium evidence*). City governments, private sector and civil society are active in mitigation. Strong political leadership is a key for city GHG mitigation (*high agreement, much evidence*). There are several sources, tools and options for city government to finance mitigation, each are applicable to different contexts.

Growing numbers of cities across the world have developed mitigation strategies or climate action plans with emission reduction targets. However, few of these strategies have been evaluated for their likelihood towards meeting targets and the effectiveness of proposed approaches (*high agreement, high evidence).*

Human settlements are faced with multiple sustainability challenges and thus mitigation strategies must address multiple agendas, including sustainable development, poverty reduction, and climate adaptation. Identifying mitigation co-benefits and spillover effects while addressing trade-offs are necessary and might increase the likelihood of success for mitigation strategies. Qualitative understanding of various urban strategies for co-benefits and trade-off in relation to mitigation is reasonably good but quantification of effectiveness is weaker in many cases (*high agreement, low evidence*).

12.1 Introduction

This chapter assesses the mitigation potential of human settlements, especially the potential of spatial planning and infrastructure. It differs from sectoral chapters 6-11 in that it treats a settlement as a whole unit (e.g., a town, a city) rather than its component parts (e.g., buildings, transport). The dominant human settlement type today is urban, and for the foreseeable future, a growing proportion of the world's population will continue live in urban areas. Urban areas also generate more than 90% of the global economy. Accordingly, the majority this chapter focuses on urban settlements. How much cities and urban areas contribute to global greenhouse gas emissions depends on the allocation method used. If emissions are allocated to the places where they are produced, then urban areas produce between 60 to 80 % of global emissions (Satterthwaite, 2008; Dodman, 2009a; Hoornweg et al., 2011a). In contrast, consumption-based allocations show a few wealthy cities contributing to a majority of the emissions. There is much debate about the appropriate method of normalizing urban emissions data so that they are comparable across cities, including by total urban population, per capita, economic base, total GDP, or density. Despite no consensus about the best urban emissions metric, there is widespread agreement that for most cities, per capita greenhouse gas emissions are a fraction of national averages. Several key parameters have the large affects on urban emissions: the spatial layout of a city, including its form and structure, density of employment and housing, infrastructure, and metabolism of the urban system.

The spatial form of how urban settlements develop — whether expansive or compact, with multifamily or single family homes, automobile dependent or transit-oriented development, with mixed- or single-use zoning — affects transportation choices and travel behaviour (Vance and Hedel, 2007; Cao et al., 2009). There is also a growing body of scientific evidence that that urban land use changes have considerable impacts on climate by altering the cycling of water, carbon, aerosols, and nitrogen in the climate system (Seto and Shepherd, 2009). The urban built environment is a significant forcing function on the weather-climate system because it is a heat source, a poor storage system for water, an impediment to atmospheric motion, and a source of aerosols (Hidalgo et al., 2008).

12.2 Human settlements and GHG emissions

This section describes the key demographic and socio-economic trends that underpin current urbanization trends, the diversity of urban centres and how this is reflected in their GHG emissions with discussions and references to rural settlements too. There are different challenges and opportunities for urban mitigation in G20 countries, emerging economies and less developing countries, as well as for expanding cities, shrinking cities, and stable cities.

12.2.1 Drivers of and process of urbanization

Urbanization is a process, one of simultaneous transformation of places, populations, economies, and the built environment in order to create an urban society (Solecki et al., In review). Scientific understanding of the drivers of urban development has improved significantly over the last decade. In addition to demographic and socioeconomic drivers, international capital and changes in urban governance and institutional structures are transforming contemporary patterns of urbanization (Seto et al., 2010).

12.2.1.1 Demographic drivers

Urban population growth in last five-six decades is unprecedented for its speed and size. The average annual rates of urban population growth for 1950-2010, by far, outpaced the global population growth rates signifying rapid urban to rural migration and the development of more urban areas. By 2009, over half of the world's population is urban (United Nations, 2010a). Between

2009 and 2050, urban areas are projected to absorb the entire world's population growth while the rural population is expected to start declining in about a decade. By 2050, urban population is projected to increase by 84 percent to 6.3 billion, from 3.4 billion in 2009, with growth concentrating in Asia (+ 1.7 billion), Africa (+ 0.8 billion) and Latin America and the Caribbean (+ 0.2 billion). Despite high level of uncertainty of these projections it is clear that the urban areas will become increasingly central in the climate debate.

Current trends in the levels, patterns and regional variation of urbanization are significantly different from those of the past. Often, comparisons across nations are further complicated because of the different definitions of what constitutes an urban area, and changes in these definitions over time (Montgomery, 2008). The urban population is currently concentrated in a few countries: in 2007, China, India and the USA accounted for 35 percent of the world's urban population (United Nations Population Division, 2008). More than 80 percent of the population in Northern America, Australia and New Zealand live in urban areas and this proportion is 73 percent in Europe and 79 percent in Latin America and the Caribbean. Africa and Asia are the least urbanized regions, with 40 and 42 percent of their populations living in urban areas (United Nations, 2010a). The expected economic growth, large populations and high average fertility are the reasons why Asia and Africa are projected to concentrate urban growth in the next decades.

Despite widespread perceptions, rural-urban migration is not a main contributor to the growth of urban populations. In India, between 1961 and 2001, urban natural growth (the excess of births over deaths in the urban population) accounted for about 60 percent of urban growth, with the remaining 40 percent due to migration and the reclassification of rural areas as urban. This is also the case with overall patterns in most low and middle-income nations; even in China, where migration is the main contributing factor of urban growth, natural growth accounts for about 40 percent (Montgomery, 2008).

12.2.1.2 Socio-economic drivers

The proportion of the population living in urban areas is inextricably linked to the expansion of the world's economy and changes in its structure. Changes in proportion of urban population reflect changes in the proportion of GDP generated by industry and services and the proportion of the workforce employed in these sectors (Satterthwaite, 2007; World Bank, 2009). The decisions of multi-national corporations on where to locate their production and where to concentrate their management also increasingly influences that shape the investment and economic opportunities in specific areas (Sassen, 2006). The economic growth strategies of national governments, including public investment in the construction of transport and other infrastructure, play an important role in the spatial distribution of private investment. In developing world urban is fast becoming key economic driver; urban India overtook rural India in GDP share in late 1990s with per capita incomes are over three times (Revi, 2008).

12.2.1.3 International capital, urban governance and institutions

International capital shapes contemporary urbanization in three ways (Seto et al., 2010). First, globalization has transformed the commercial property market from a local to international industry (Fuchs and Scharmanski, 2009). Real estate developers and property management firms have become a major presence globally, and contribute to the development of high-rent industrial and residential facilities built in a "global modern" style that can be around the world from North America and South Asia (Reilly et al., 2009) to Central Europe (Keivani et al., 2001). Second, the building, infrastructure, and human resource demands of multinational corporations, especially technology and science industries, requires the construction of facilities with specific physical infrastructure and amenities (Mae Phillips and Wai-chung Yeung, 2003). Third, international capital is changing urban form through the influx of an international workforce who often prefer single family housing, thereby encouraging dispersed, unplanned, and uncoordinated urban development in cities around the world from Warsaw (Keivani et al., 2001) to Shanghai (Wu, 2008).

12.2.2 Range of human settlement types

The most common characteristic used to describe and categorize human settlements is population size. For example, megacities are defined as urban agglomerations with more than 10 million inhabitants. Cities with between 1 and 5 million inhabitants account for 22 percent and smaller cities with between 500,000 and one million inhabitants account for 10 percent of the overall urban population. 51.9 percent of world's urban population live in urban centres with less than 500,000. In addition to population size, settlements can be classified by their spatial extent and form. However satellite-based efforts at mapping global urban extents fail to agree on the size and pattern of urban land use, with estimates ranging from 0.2% to 2.4% of terrestrial land surface circa 2000 (Potere and Schneider, 2007). Similarly, there is a range of estimates about urban forms globally, but general consensus is that urban areas are increasing less compact and more dispersed (Schneider and Woodcock, 2008; Seto et al., 2010, 2011; Angel et al., 2011), with urban extents growing faster than the rate of urban population growth (Seto et al., 2010).

A high proportion of urban settlements – accounting for 13 percent of the world's urban population - are located in low elevation coastal zones (McGranahan et al., 2007). In fact, over the last thirty years, urban areas in low elevation coastal zones are growing faster than urban settlements elsewhere (Seto et al., 2011).

Urban areas contribute to a disproportionate percentage of the global economy. At the turn of the 19th century, more than 80 percent of the global economy was generated by the agriculture (Pablo, 2007). Today, it is urban areas that generate more than 90 percent of the global economy (Pablo, 2007).

12.2.3 Urbanisation, cities and emissions trends

GHG emissions from human settlements are results of human service demand for access (mobility), food, space conditioning, shelter, social interactions, leisure, education and others and thereby to increase the quality of life (Ausubel and Herman, 1988). The scale and intensity of these demands and the associated choices of infrastructure, energy mix and technology determine settlement's GHG emissions. However, a settlement do not always caters to its internal demand and consumption of its dwellers but also plays important role in production system and economy that are linked to the region and the broader level. Long established settlements have often have high inertia and path dependency with distinct urban form, functions and infrastructure, while in emerging settlements, initial conditions that influence GHG emissions (such as urban form and other dimensions of spatiality, urban function, infrastructure choice etc.) are being actively negotiated along their economic, social, environmental goals.

12.2.3.1 Rate, scale and location

The speed (i.e. rate), scale and location of urbanisation (characterized by demography, economic, land use change, societal factors) are determined by several local, regional and global factors. Impact of urbanization (characterized by urban population share) to global CO2 emission is visible. A recent study shows that the elasticity of urbanization with respect to global primary energy use and CO2 emission from energy use stands close to zero and 0.4 respectively for 1975-2005, meaning no apparent impact of urbanization to energy use but significant implications to CO2 emissions (Poumanyvong and Kaneko, 2010). Such relationship are shown to varies across various income groups with urbanization reducing energy use but increasing CO2 emission in low income countries due to faster ascendance to fossil fuel from biomass in the energy ladder. In middle and high income countries, urbanization is shown to increase both energy and CO2 emissions but the difference within the impacts of urbanization to energy and emission in high income countries are more pronounced where impact to energy is greater than emission signifying greater penetration of cleaner energy (Poumanyvong and Kaneko, 2010). Another recent study shows that urbanization could "lead to an increase in projected emissions by more than 25 percent in the future, particularly in developing country regions, mainly through effects on labor supply" (O'Neill et al., 2010). One clear point of differences in conclusions regarding effect of urbanization on global CO_2 emissions can arise from the differences in the definition of urbanization which do not have only demographic dimension but also many others (Dodman, 2009b; O'Neill et al., 2010).

Estimation by International Energy Agency shows that the urban areas contributed 67 percent and 71 percent to the global primary energy demand and energy-related CO_2 emissions in 2006, respectively (IEA, 2008). The contribution of urban area in this CO_2 is estimated to increase to 76 percent by 2030. Regional variations are enormous; carbon emission from urban energy use for China is 85 percent, USA is 80 percent and Europe is 69 percent (IEA, 2008; Dhakal, 2009; Parshall et al., 2010). Another recent study follows a different approach. Following the downscaling technique (for methods and data sets see (Grübler et al., 2007)) developed for spatially-explicit GHG emission scenarios, the study shows that urban areas contribute between 56 percent and 78 percent (central estimate: 76 percent) of total final energy (as opposed to primary energy use as used in WEO 2008) showing a reasonably good agreement between studies at the global scale (Grubler et al., 2011). These studies highlight the importance of paying attention to the definitions of the urban population, the urban extent, and the city. Depending on the definition used, the urban energy and carbon estimates can vary substantially (Dhakal, 2010b). For example, for the US, 76 percent of the direct final energy consumption occurs in 'census urban areas', 59 percent occurs in 'urbanized areas' and 17 percent occurs in 'urban clusters' (Parshall et al., 2010). Furthermore, the difference of urban contribution could also result from how out-of-boundary electricity is treated (Bottcher et al., 2012).

For GHGs other than CO_2, global contribution of urban area is unknown. It can be fairly said that the urban GHG contribution globally would be far lesser than 71 percent as in the case of energy-related global CO_2. This is because the annual average share of energy-related CO_2 emissions globally for 2000–2009 is about 90 percent only; the remaining is from the land use change (Friedlingstein et al., 2010) to which urban areas are not expected to contribute much. Although being far from accurate, one study shows perspectives that the urban'' contributions to global methane emissions are far lesser (Wunch et al., 2009). One study deducts the possible non-urban sources from global GHG emissions and guesstimates urban contributes in the range of 30-40%; in this, CO_2 in electricity that come from outside of cities is essentially excluded (Satterthwaite, 2008).

Across cities, existing studies point to a large variation in the magnitude of the total and the per capita emissions and such differences emerge from the multiple factors such as nature of emission sources, 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 other factors (Dhakal, 2004, 2009; Carney et al., 2009; Kennedy et al., 2009; Kennedy, Ramaswami, et al., 2011; Aumnad, 2010; Gomi et al., 2010; Li et al., 2010; Shrestha and Rajbhandari, 2010; UN Habitat, 2011). The importance of one factor over others or of a set of factors for different city settings has not been well analysed and established. In the United States, for only transport and residential sectors, per capita carbon emissions were highest in Lexington (3.5 tons) and lowest in Honolulu (1.4 tons) in 2005 within 100 metropolitan areas (Brown, Southworth, et al., 2008). In developing country big cities such as in 35 cities in China (Dhakal, 2009) and Bangkok (Aumnad, 2010) they have disproportionately higher CO_2 emission share as compared to their population. While in cities such as Tokyo, London, Toronto, New York, and many others in developed countries, their per capita emissions are smaller than the nation. The overall patterns of cities' CO_2 emission are yet less studied to conclude on city typology and their GHG implications. Often, comparing only city emissions between and within the developed and developing counties without considering the underlying factors is not prudent since each city has distinct geographical, economic, socio-cultural and functional contexts. Important of one variables over others for a particular city are shaped by multiple factors; for example the influence of population density effect on GHG over income effect might be higher in cities in developed countries than the developed countries.

12.2.3.2 Measurement and metrics

There are neither agreed common methodologies for urban GHG emissions nor agreed framework (including, boundaries) of emission estimation for a city. In global, regional and national scale urban carbon studies, the GHG estimation is sensitive to the definition of urban area or urban population and accounting principle. At city scale, the measurement of GHG emission confronts several factors such as the methodological diversity, data scaling, the scope of emission sources, the definition of city, the attribution of activity boundaries in emission estimation, and others (Bader and Bleischwitz, 2009; Dhakal, 2010b; Kennedy, Ramaswami, et al., 2011). GHG emissions studies on cities frequently use IPCC Inventory Guidance which is essentially territorial, in principal, and relies on emission factors and the scale of activities. GHG emissions from waste often constitute a small fraction only and, in many cases, waste treatment facilities are located outside cities too. How to treat emissions from activities such as for aviation, marine transport, transit mobility, distribution losses in electricity is yet an open question.

A majority of urban GHG estimates are available at administrative definition of city rather than the urban agglomeration. Municipal government that are known as "the city" could only account for a fraction of urban agglomeration and miss out the true characteristic of the urban area (examples, Dhaka, Bangkok, Manila, Tokyo etc), while in few others they also represent a large swath of rural areas (example, cities in China).

Cities' GHG emission measurement methods could be multiple, each of which has its own strength to explain cities' GHG performance and the mitigation opportunities. All the GHG discussions made above are from production viewpoints; this means allocating GHG at the point of emission. Despite not being fully territorial emission, CO2 from all electricity and heat are accounted in the city estimates in most of the city analyses and the GHG inventories of city governments. There are only a few studies to show concrete evidence of how cities would compare if GHG is attributed to consumption side but the basis on which GHG responsibility of cities should be determined are open questions (Kaneko and Dhakal, Under Preparation; Dodman, 2009b; Hoornweg et al., 2011a). See section 12.4.2 for further discussions. Early indications are that, if CO2 is allocated to consumption side cities may not remain of low per capita emission in developed countries compared to the nation, that we get impression from production based carbon allocation criteria. For commercial cities, such emission, if ignored, may underestimate cities' GHG contribution and the ability to influence consumption for either avoiding or reducing carbon emissions upstream. For examples, Tokyo has per capita CO2 far lower than the national average but exceeds the national average if CO2 is attributed to the consumption side (Kaneko and Dhakal, Under Preparation). Such emission (attributed to consumption side) pattern for UK municipality across the country is closely related to the distribution of wealth across private households, and in the city such as London, such CO2 is several times of that officially reported by Greater London (SEI, 2007; Minx et al., 2009).

For scaling up knowledge on GHG and urban areas, a better understanding of urban development pathways, GHG across different city typology and multiple way of GHG accounting, and across the different physical boundary of the agglomeration are necessary.

12.3 Urban structure, form and infrastructure

In this chapter, 'urban structure' refers to the spatial organization of settlements, particularly, the geometrical characteristics established by the relationship between the primary elements of public structure (e.g., green space, movement of all modes, public institutions, hard urban space and utility services). This geometry is essentially a two-dimensional term and has strong implications for land-use. 'Urban form' is both two- and three-dimensional, which refers to the footprint of settlements and the spatial totality of built elements and voids which make up a settlement, respectively. 'Infrastructure' refers to both utility and social services; the distribution of utility services has the most powerful impact on urban form. The form and structure of human settlements are two of the major factors that determine energy use and emissions through the layout of streets and buildings, accessibility to jobs and markets, infrastructure investments, and transportation corridors. Once in place, the basic spatial structures of human settlements are difficult to change. This section assesses the impact of urban form, structure, and infrastructure on greenhouse gas emissions.

12.3.1 Drivers of urban structure and form

The drivers of settlement structure and form are complex. Some of the most important ones which have implications for greenhouse gas emissions include:

• Human behaviour. There is also a connection between affluence and consumption patterns: the greater the affluence, the higher the consumption. Affluence also results in increased freedom of choice. For example, the rise of single family homes as preferred housing in many cities around world was only made possible by increasing access to private motor vehicles which, in turn, has entrenched the use of the private motor vehicle.

• Economic base. Manufacturing and industrial cities have more low-rise and expansive form than service and financial cities, which tend to be more vertical and compact. The essential distinction is between industrial towns and cities versus service- and knowledge-based cities is that the former will have high production-based emissions while the latter will have high consumption-based emissions.

• Patterns of investment in public infrastructure, particularly utility infrastructure. There is a strong 'lock-in' factor associated with public infrastructure: it powerfully informs private sector. At the same time, private sector investments are increasingly a factor in shaping public investments. Together, they strongly influence future patterns of growth.

•Technology. Technological change, particularly in movement and transport, significantly impacts on structure and form.

12.3.2 Characteristics of urban structure and form impacting on GHG emissions

There is a strong and direct correlation between urban structure and form and greenhouse gas emissions. Structure and form are responsible directly for a large proportion of consumed energy and they influence indirectly the patterns and modes of energy consumed in everyday activities (Rickwood et al., 2008). There are several key, interrelated, characteristics of structure and form which impact on greenhouse gas emissions.

12.3.2.1 Population density

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

The most common explanation for the correlation is that VMT decreases with increasing density while public transportation use and efficiency increases with density (Rickwood et al., 2008). While there is widespread agreement about the correlation between density and VMT, there is far less agreement about causality (Badoe and Miller, 2000; Rodriguez et al., 2006). A study of travel distances in the USA has found a range of elasticities of travel distance around factors such as street design, diversity, distance to transit, and density (Ewing and Cervero, 2010). It is difficult to establish causality because transport and land use are not independent but are complexly interrelated. High population densities and compact urban design are required to support mass transit alternatives to the automobile.

There is a fairly widespread agreement about the correlation between density and modes of movement. Lower densities entrench the use of the private motor vehicle. Longer distances make modes such as walking and non-motorized transport less attractive, while public transportation (a necessary alternative if private vehicular flows are to be reduced) cannot exist without minimum levels of support (Frank and Pivo, 1994). While there are significant variations caused by other factors (particularly income), there is a clear but non-linear association between higher densities and greater public transportation use, with the largest effects taking place at up to 70 people per kilometre, beyond which returns are marginal (Rickwood et al., 2008). Urban structure and form are part of the explanation for the differences between Europe's comprehensive and well-patronised public transportation systems (Goodwin et al., 1991) and the limited, poorly patronized systems typical in North America and Australia (Kenworthy and Laube, 1999) and in sub-Saharan Africa (Dewar and Todeschini, 2004). An additional consequence of more expansive urban forms is that utility service runs are considerably longer than in more compact forms, thereby significantly increasing direct and embodied energy use and thus greenhouse gas emissions.

There is a growing, but by no means uncontested (Neuman, 2005) literature that argues that more compact forms are more efficient on multiple fronts (Burchell et al., 1998; Jenks and Burgess, 2000; Ewing et al., 2001; Glaeser and Kahn, 2004; Jenks and Dempsey, 2005). For example, it has been found that as sprawl decreases, then average vehicular ownership, daily VMT per capita, annual traffic fatalities and maximum ozone levels also decrease significantly (Ewing et al., 2001). Further compaction has a number of significant co-benefits in terms of increased convenience, savings in terms of commuter costs and improved public health. The US National Research Council has found that compact urban development coupled with high residential and employment densities can reduce energy consumption, vehicle miles traveled, and carbon dioxide emissions (National Research Council, 2009).

Many countries, for example, the United Kingdom, Denmark, South Africa, have introduced urban containment policies. These are generally of two kinds: policies aimed at preventing, or at least slowing down, lateral spread; and policies aimed at strategic infilling or densification. Two forms of densification are: infilling around nodes of existing urban opportunities and public transportation stops or interchanges (Transit-Oriented Development), of which London UK is an example; and the promotion of urban corridors (Curtis, C. and Tiwari, R., 2008; Dewar, 2010). Curitiba in Brazil is an oft-quoted example of the latter.

A significant barrier to policies of this kind in market-driven economies is land price. In these economies, land prices reflect, at least in part, trade-offs in terms of transportation costs (Muth, 1969): the lowest prices tend to be on the urban periphery. This is a particular problem when levels of poverty are high. Many of the poorest households, who can least afford high transportation costs, can only obtain access to land on the periphery: the system contributes to a self-perpetuating cycle of poverty.

There are, however, climatic tradeoffs from compact urban development, particularly in the form of urban heat islands (UHI) (Oberndorfer et al., 2007). Potential mitigation measures for UHI include the use of lighter coloured materials, particularly on roofs (Rosenfeld et al., 1998); planted roofs (Alexandri, E. and Jones, P., 2008), the use of shade trees (Akbari et al., 2001), energy management (Dhakal and Hanaki, 2002) and urban design measures such as the orientation and widths of streetscapes, the use of buildings to create shade and the creation of paths (McPherson, E. G., 1994; Rosenfeld, A.H. et al, 1995).

12.3.2.2 Tendencies toward linearity

There is a tendency in cities for more intensive activities, such as those activities requiring public support, to gravitate towards more continuous routes carrying public transportation, thus forming activity corridors – bands of higher density, more mixed uses (Curtis, C. and Tiwari, R., 2008). This form reduces vehicular generated greenhouse gas emissions by increasing the use of public transportation.

12.3.2.3 Economic density and land use mix

In centralized settlements, economic activity is clustered in a limited number of places, and in polycentric urban forms, economic activity is decentralized. Polycentric forms reduce aggregate amounts of movement and thus vehicular-generated greenhouse gas emissions (Cervero, 1995). The increasing emphasis on 'knowledge economies' based on information technology contributes to this by making possible more work from home, and thereby reducing VMT associated with commuting (Shuller, 2000; Deakin, M., C. Reddick, 2010). Similarly, more mixed-use settlements tend to reduce aggregate amounts of vehicular movement more than settlements characterized by high degrees of deprivation and mono-functionality. They also promote walking as opposed to vehicular travel (Parmera et al, 2008).

12.3.2.4 Grain and scale

Settlements with a fine-scaled urban fabric (where buildings are close together, the block dimensions are small and streets are narrow) promote walking more than coarse-grained settlements. There are a number of reasons for this: distances to be walked tend to be less; and the system of small blocks enables the pedestrian to change direction easily, a factor which promotes convenience. Related to this is the quality of the public spatial environment. Walkable neighbourhoods in which walking and other forms of non-motorized transport are pleasant experiences foster the use of NMT and public transport modes (Gehl, 2010). Design, therefore, is important for encouraging alternative forms of transportation.

12.3.2.5 Connectivity

Settlements in which the movement system is more neutral and interconnected (such as the grid) and those which are destination-based, in the sense that they emphasize a limited number of points only, such as radial systems, have different impacts on travel demand, energy use, and emissions. The propensity for congestion (a significant factor in the generation of vehicular-generated greenhouse gas emissions) is much greater in the latter. When large numbers of vehicles are trying to enter one point from a limited number of routes, the almost inescapable outcome is congestion. In more neutral systems, vehicular flows tend to dissipate, as drivers seek alternative routes.

12.3.2.6 Building form and height

Building height is an important dimension of urban form. Together, housing and transport-related energy account for over half the energy use of a typical household. Both are significantly influenced by urban and spatial planning policies. These two forms of energy use need to be viewed in combination. Without this, cities run the risk of simply redirecting energy use overall.

The operational energy requirement of buildings is a function of climate, design, quality of the building stock, location (Weisz and Steinberger, 2010), as well as orientation and height. Semi-detached and three storey buildings have been shown to be significantly more efficient in terms of operational energy, than single storey, free-standing units, while high rise buildings are the most inefficient, largely because of the use of the elevator (Myors et al., 2005). Thus, while the independent effect of building type may be relatively small, significant total energy savings may be possible through a combination of dwelling type, design, location and orientation.

12.3.2.7 Carbon sinks

The amount and distribution of green open space impacts on greenhouse gas emissions. The carbon sink function of green space is affected by urban structure and form, although impacts have different interpretations depending on the scale of observation. If the focus is exclusively intra-city, more compact forms can have a negative effect on green space within its boundaries. Furthermore, high density means that the points of discharge of urban wastes is very intense, inevitably creating far more severe impacts than when the impacts are spread over a broader area (Neuman, 2005). In the case of more dispersed forms, small pockets of public green space and large amounts of private green space remain, albeit in artificial or manufactured forms. Despite the fragmented nature of these spaces, many of nature's biophysical processes remain intact.

When the scale of observation is more regional, however, more compact forms have strong advantages as their physical footprints are more limited: they seldom destroy entire ecologies. More expansive urban forms have the potential to destroy or convert entire biospheres.

Although the impact of urban green space in reducing greenhouse gas emissions is relatively minor, it is a low hanging fruit, in the sense that it has significant co-benefits such as increased recreational space, improved mental and physical health, and aesthetic improvement. Cities such as Stockholm, Sweden, and eThekweni (previously Durban) in South Africa are currently engaged in large tree-planting programmes under the banner of climate change mitigation (Rosenzweig et al., 2011; ASSAF, 2011).

12.3.3 Opportunities and barriers to mitigation

There is great potential for mitigation through the manipulation of urban structure and form. It is quite possible to do this through intelligent and creative planning and political commitment. The potential opportunities for savings in GHG emissions are greatest in contexts where urban growth is rapid (that is, in less developed countries), as opposed to cities where growth is slow or even stagnant. Ironically, however, change is least likely to occur in these fast growing settlements, where significant barriers exist in the form of a lack of political will, weak leadership, low capacity relative to the range of challenges which these settlements face, and inadequate finance.

Transit oriented development (TOD) strategies that integrate moderate to high density development featuring a mix of residential, employment and shopping opportunities for pedestrians and cyclist can achieve the dual objectives of reducing car dependence and preventing expansive development. Although land use planning might have limited effectiveness in reducing GHG emissions in the short run, it can be a very effective means in the long run to mitigating climate change via relocation of land use activities to reduce travel distances and the development of new public transport infrastructure to reduce transport volumes.

12.4 Urban systems: activities, resources, and performance

Urban settlements are fundamentally open systems. Therefore, they can lower their local emissions while helping lower emissions outside of their administrative boundaries through their use of materials and resources. As a complex system, cities can increase the efficiency of infrastructure and energy use beyond what is possible with individual sectoral components. This section assesses the mitigation potential of urban systems by taking a whole systems perspective, incorporating urban metabolism and the flows of resources and energy.

12.4.1 Conceptual framing of urban systems and GHG implications

12.4.1.1 Global system definition: linkages between sectors through resource flows

Human settlements and infrastructures play an essential role in facilitating human activities such as shelter, work, transportation, communication, food, and sanitation (Baccini and Brunner, 1991). Human settlements are metabolic systems that depend on the environment for resource extraction (e.g., water, minerals, air) and emission absorption (wastewater, solid waste, and off-gas) (Figure 12.1). The individual sectors of these systems (agriculture/forestry, industry, energy supply, buildings, transportation, and waste management) are linked with each other through physical flows of goods (e.g., resources, products, or emissions). The linkages between sectors has significant implications for climate change mitigation: interventions in any of these sectors have consequences for the other sectors and the environment. For example, the renovation or replacement of the building stock has consequences not only for direct energy demand and emissions, but also for industrial activity (e.g., materials production), waste management (e.g., urban mining of obsolete structures), which in turn shapes boundary conditions for primary resource extraction and energy saving through recycling or reuse. An adequate understanding of socio-metabolic systems is necessary in order to identify transformation pathways for human settlements that reduce overall GHG emissions while minimizing risks of declining access to resources and consequences of other emissions. A systemic view can provide policy makers with more robust information about long-term changes, relevant drivers, and consequences of alternative mitigation strategies, including potential co-benefits and trade-offs with strategies for urban development, industry, resource conservation, security of supply, and pollution control.

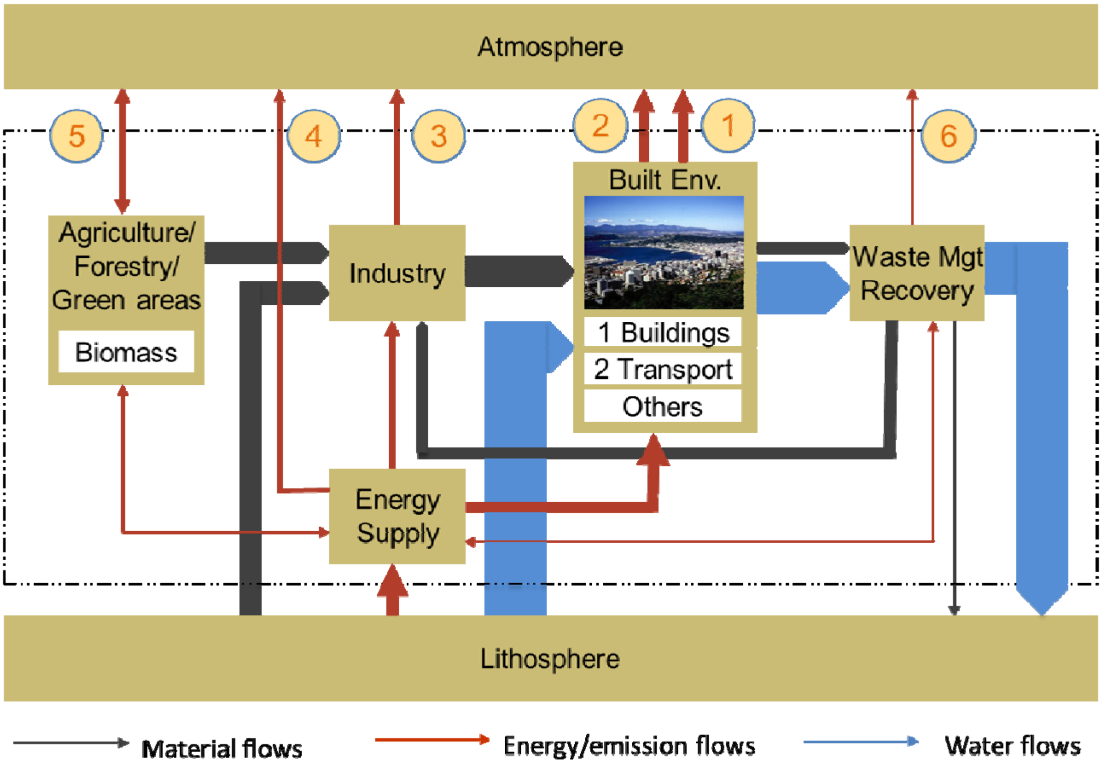


Figure 12.1 Human settlement sectors, their emissions, and linkages through flows of energy (red), materials (black), and water (blue). (GHG emissions per sector will be quantified for all sectors using data from the Edgar database).

The development of human settlements affects not only the GHG emissions related to buildings (33% of global energy and process related CO2 emissions) and transport (23%), but also industry (36% in total); human settlements – in particular buildings, transport infrastructures, and vehicles – embody most of the materials processed in industry, which account for more than half of all industry emissions (Figure 12.2). Steel and cement production alone constituted about 16% of the total energy and process related CO2 emissions in 2006, which is in the same order of magnitude as private transportation.

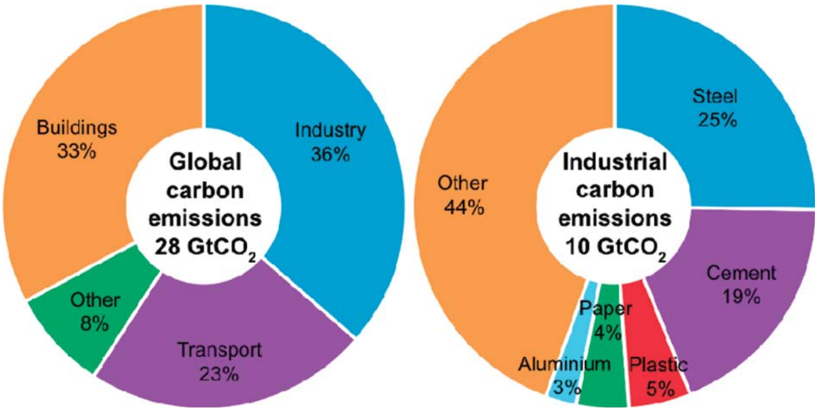


Figure 12.2 Global energy and process related CO2 emissions by sector, 2006. Source: (Allwood et al., 2010).

12.4.1.2 Temporal dimension and the evolution of the built environment stock

Human settlements and infrastructures development patterns define the boundary conditions for mitigation efforts over several decades in multiple ways: (i) the long lifetime of built environment structures limit the speed at which emissions in the use phase (e.g., buildings and transport) can be reduced; (ii) their build-up requires large amounts of primary resources that contribute to industry emissions; and (iii) once these structures have reached the end of their lifetime, the materials they embody may be recovered for reuse or recycling ("urban mining"), which not only saves primary resources and waste, but often also large amounts of energy and emissions in industry and energy supply. The growth phase of built environment stocks (mainly during rapid urbanization) is therefore particularly energy and emission intensive. For example, China, which is currently undergoing a rapid urbanization phase, accounted in 2009 for about 46% of global steel production and for about 54% of the global cement production (U.S. Geological Survey, 2011) although residents of China constituted only about 19% of the World population. (Minx, Baiocchi, et al., 2011) show that the rapid CO2 emission increase in China between 2002 and 2007 was caused by a change in China's economic structure towards carbon intensive activities (such as cement and steel production) associated with the supply chain of the construction industry. Growth patterns of built environment stocks are therefore important factors for explaining emission pathways.

The growth of individual infrastructures is often hypothesized to follow an S-shaped penetration curve with a lifecycle from the early development phase through the rapid growth and expansion phase to the eventual saturation phase (Ausubel and Herman, 1988). Statistical evidence in support of this hypothesis has been found on absolute, but more clearly on per-capita levels, for canals, railways, and roads in the U.S. (Grübler, 1990), bridges in Norway (Hammervold et al., 2012), and water and wastewater pipelines in Oslo (Venkatesh and Brattebø, In Press; Ugarelli et al., 2008). Vehicle ownership tends to flatten in industrialized countries although no saturation can be observed yet (Pauliuk et al., 2011). Floor area of residential buildings is still expanding even in rich countries, although often with a declined growth rate (Müller, 2006; Bergsdal et al., 2007). The potential saturation of individual infrastructures does not necessarily result in a saturation of the overall built environment stocks because new infrastructures continue to arise, such as high-speed rails, Internet, or new energy systems. Such new infrastructures, mainly related to electronics, alternative energy systems, and clean technology, often tend to involve materials that are considered critical for their supply (Kojima, 2002; Committee on Critical Mineral Impacts of the U.S. Economy, Committee on Earth Resources, National Research Council, 2008; European Commission, 2010) or that can cause local environmental problems in mining and refining (e.g., water resource depletion). However, these new infrastructures have a comparatively small impact on overall material stocks and corresponding GHG emissions.

For iron and steel, saturation of per-capita stocks have been observed for the U.S. (9-11 tons), the U.K. (ca. 7-9 tons), and France (ca. 7-9 tons), however, no saturation has been reached yet in Japan (12-14 tons), Australia (9-11 tons), and Canada (11-13 tons). Japan employs increasing amounts of steel in infrastructures and buildings due to the high density of its settlements (e.g., large share of steel-intensive high-rise buildings) and to protect the structures against earthquakes. Australia and Canada have a very low population density, but have large and growing mining infrastructures, including rails, to transport ores from remote places to harbours for shipments to emerging market economies (and thereby take part in the urbanization and industrialization of emerging market economies), which could potentially explain their continued growth in iron and steel stocks (Müller et al., 2006; Müller et al., 2010). Estimates for the average global iron stocks in use range from 2.0 (Hatayama et al., 2010) to 2.7 tons per capita (Müller et al., 2010). For aluminium, no saturation of per-capita stocks has been observed yet, although stock growth tends to decline in industrialized countries (Hatayama et al., 2009; Liu et al., 2011). This continued stock growth can be explained by the fact that aluminium is increasingly used in automotive applications to reduce weight and save energy in the use phase. No detailed view exists yet for historic cement stocks in various countries. The cement stock in the U.S. is still growing on a per-capita level (currently 14-16 tons) (Kapur et al., 2008).

Growth patterns of human settlements and their embodied material stocks play a crucial role for GHG emissions and mitigation strategies. It is estimated that 1,527,000 km^2 of land area, or approximately the size of Mongolia, will become urban by 2030 (Seto et al., 2011). During rapid urbanization, industry emissions (e.g., to produce the materials needed for construction) tend to be much higher than in phases of maturation or shrinkage. The growth or shrinkage rate is therefore a key factor to consider when comparing emissions between different cities.

(Müller et al., 2012) estimated that the emissions embedded in the materials of settlement structures in more developed countries are 20-30 t CO2 per capita compared to 1-10 t CO2 in less developed countries, assuming currently available technology for the material production. They conclude that in a scenario of rapid urbanisation in developing countries over the next decades, emissions of the materials production (largely based on primary resources) would become a key factor for climate change mitigation, potentially hampering the possibility of reaching the 2°C target by 2050, and that developing countries have a potentially large, but still poorly understood leapfrogging potential of building their settlements and infrastructures with high service quality, but with less emission-intensive materials than the more developed countries have done.

12.4.2 Urban systems and their hinterlands

Cities are open systems that depend on their hinterlands in terms of imports (e.g., resources, products for industrial production or final use) and exports (e.g., emissions, manufactured products). As supply chains are becoming increasingly global in nature, so do the hinterlands of cities. For example, cities are characterized by a high concentration of buildings, infrastructures, and transport activities, but they are seldom involved in mining, materials processing, and resource- and emission-intensive manufacturing is highly variable among cities (Satterthwaite, 2008). The openness of cities leads to questions about the allocation of responsibility for greenhouse gas emissions and the appropriate choice of the system boundaries for emissions accounting (see 12.2.3.1). Since cities only have legislative power within their administrative boundaries, the territorial approach may often be seen as the only enforceable strategy (UN Habitat, 2011). However, by following exclusively a production-based approach, the opportunities of cities to influence the large upstream emissions are ignored, the role and responsibility to the consumers towards GHG mitigation is underestimated, and emission-shifting behaviour of cities are unchecked for. Cities can play a more important and constructive role in climate change mitigation if they do not limit their efforts to reducing their own emissions, but if they engage in efforts to lower global emissions, which involves a dual strategy of implementing local actions and taking responsibility for the entire supply chains of imported and exported goods. For example, urban mining may slightly increase a city's carbon emissions, but it may help other (urban or rural) regions to substantially lower their carbon emissions through recycling or reuse of the recovered scrap. The following sections discuss the use of metabolic concepts on an urban scale for reducing emissions from a territorial and consumption perspective.

12.4.2.1 Metabolism of urban systems

Since the 1990s, an increasing number of urban metabolism studies have been conducted, mainly for cities in developed countries. A key insight from urban metabolism that can be brought to bear on mitigation is the identification of leverage points and opportunities in an urban system where energy and resource use efficiency can be increased. While most urban metabolism research has focused on flows of materials, energy, and emissions, some studies have an explicit focus on built environment stocks, their composition, and the associated energy use and emissions for their construction. Such studies can inform policies with a long-term focus and with spatial dimensions. In Australia, low-rise medium density houses were found to be less energy-intensive in construction than detached houses due to savings in shared walls, economies of scale, and surface area to volume ratio. However, for buildings higher than three storeys, the embedded energy per floor area rises due to exponentially increasing structural demands (Treloar et al., 2001; Rickwood et al., 2008). In Germany, a more systematic approach was used to develop typologies for buildings (Gruhler et al., 2002; Dirlich et al., 2011) and urban settlements including their corresponding infrastructures on a block or neighborhood scale (Blum and Gruhler, 2010). In China, efficiency gains in building construction and operation were outstripped by the magnitude of urban development and the association rise in adoption of high energy consuming appliances such as air conditioning (Güneralp and Seto, 2012b). Such typologies can serve as a basis for the assessment of urban development alternatives with respect to material and energy flow implications on an aggregate level.

12.4.2.2 Consumption approach

Consumption-related GHG emissions are usually determined using a life cycle analysis (LCA) framework. The carbon footprint of individual products can be derived as a by-product of LCAs. Corporate emission accounting using the WRI/WBCSD approach distinguishes three types of emissions: Scope 1 (direct emission), Scope 2 (indirect emission embodied in electricity and heat) and Scope 3 (embodied emissions in resources use). Scopes 2 and 3 can be quantified using a LCA approach. Similarly, an LCA framework can be used to compute the upstream emissions of imports into cities. (Ramaswami et al., 2008) demonstrated that a hybrid approach (combining process- and IO-LCA) can be used to determine the GHG emission embodied in a few key material flows in urban areas. There are suggestions that process-based LCA may not be the best approach to consumption related GHG emissions of municipal services and communities, among others because of data availability (Junnila, 2006; Larsen and Hertwich, 2010). IO analyses have long been used for evaluating boundary GHG issues at the national context. Few applications have been conducted so far for cities, however, carbon footprint analyses using an IO-LCA approach have been building up quickly in the last few years (Kaneko and Dhakal, Under Preparation; Lenzen et al., 2004; Minx et al., 2009; Larsen and Hertwich, 2010).

Upstream emissions for fuels and materials in final products are usually not included in inventories for most cities (see section 12.2.3). Carbon footprint is commonly used in scientific literature to trace both the direct and indirect GHG impacts. CO2 emission attribution to the consumption side of goods and services is a key aspect in determining the urban carbon footprint. The consumption approach assigns the GHG emissions released globally in the production of goods and services to the location of final consumption (Peters, 2008). A good overview of applications at different scales is provided by Minx et al. (2009) and Peters (2010).

Most carbon footprint analyses have been conducted so far on the national level and this literature provides evidence for a growing spatial disconnect between the locale of final consumption and the locale of production of consumable items in recent years. Global emissions from the production of exported products have increased from 4.3 Gt CO2 in 1990 (20% of global CO2 emissions) to 7.8 Gt

CO2 in 2008 (26%) (Peters et al., 2011). With continuing international trade integration the way CO_2 emissions are accounted for is becoming increasingly important. (Lenzen and Peters, 2010) show how consumption activities in the cities of Melbourne and Sydney trigger the releases of CO2 emissions throughout Australia.

The importance of international trade related CO_2 emissions tends to increase with decreasing country size. Figure (left) finds a linearly decreasing relationship between a country's emission share associated with export production and population size. Similarly, Figure (right) shows a linearly decreasing relationship the share of "imported" emissions and the area of a country. This evidence therefore indicates that the smaller the territorial boundary of a spatial entity, the more important the role of that entity might be in the global system of production and consumption.

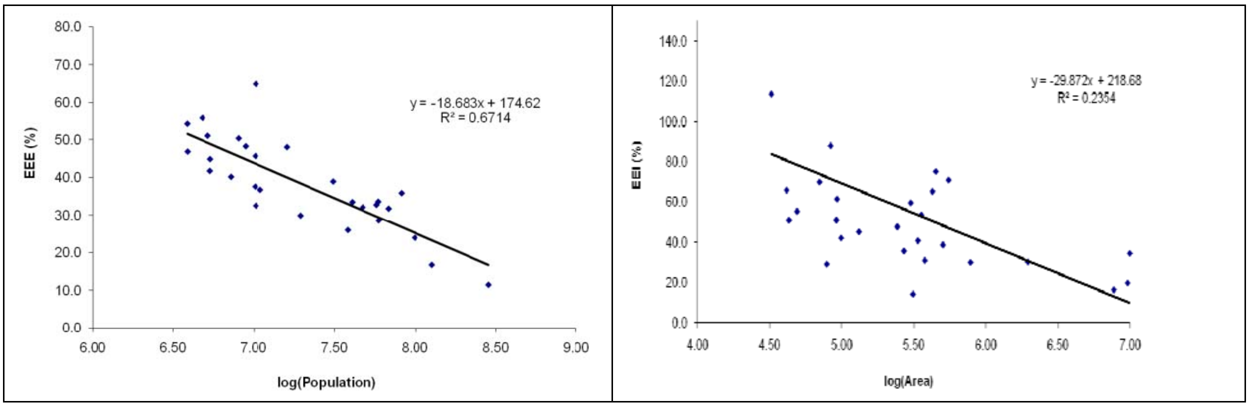


Figure 12.3 Emissions embedded in exports and imports as a function of population size and area, derived from data provided in (Hertwich and Peters, 2009). Source: (Hertwich and Peters, 2009).

Carbon footprint analyses for smaller spatial scales, such as cities or towns, are still in their infancy (Kennedy et al., 2010; Ramaswami et al., 2011) and there is very limited empirical evidence available (Minx et al., 2009; Weisz and Steinberger, 2010; Minx, Creutzig, et al., 2011). Consumption-based CO_2 emission accounts are available for selected cities (Heinonen and Junnila, 2011a; c); more comprehensive datasets exist for the UK and Australia (Minx et al., 2009; Lenzen and Peters, 2010).

This initial evidence suggests that income is the main driver of consumer emissions at the local level. Furthermore, consumer emissions are rather driven by socio-economic rather than spatial drivers (Heinonen and Junnila, 2011a; b). There is no clear distinction between the global CO2 emissions associated with rural and urban consumption. While the average urban areas show a slightly lower carbon footprint than the average rural area in the UK, the range in carbon footprints for urban areas is also substantially larger. Due to similarities in lifestyle across the UK, consumer emission estimates show much lower variation than territorial estimates (Minx, Creutzig, et al., 2011). In Finland, urban carbon footprints for two metropolitan areas were estimated to be higher than the rural ones (Heinonen and Junnila, 2011a). In Tokyo, consumption based carbon is several time higher than the production based accounting (Kaneko and Dhakal, Under Preparation). In developing countries, however, urban carbon emissions tend to be larger than in rural regions due to the higher incomes and associated consumer spending in urban areas (GEA 2012).

12.4.3 Urban sectors mitigation potentials for direct and indirect emissions

Urban areas can reduce GHG emissions (or store carbon) in all sectors – transport, buildings, industry, energy supply, agriculture/forestry/green areas, and waste management (see Figure 12.1), although agriculture/forestry/green areas are usually less important in urban areas. Direct emissions under the control of cities may be of six types: landfill gas (methane), wastewater treatment (methane, nitrous oxide), fugitive and process emissions (typically from refrigerant or electricity distribution equipment, e.g., HFCs, PFCs, SF6), fuel combustion (CO2), vehicles (CO2), and direct energy generation (Local Government Operations Protocol 2008, WBCSD, WRI GHG Protocol 2007). For GHG inventory purposes, residential, commercial, transport, waste and industrial sectors are usually considered. Local government's own emissions are often through municipal facilities, water delivery facilities, wastewater facilities, solid waste facilities, vehicle fleet, transit fleet, and employee commute and others (LGOP, 2008).

A key challenge for achieving deep emission cuts lies in the fact that the sectors are not isolated, but linked through material flows: interventions for reducing emissions (either related to urban form or specific sectors) can lead to significant changes in the material cycles (e.g., material demand for new technologies or infrastructures, secondary resource availability from obsolete structures with opportunities for recycling), and the changing material cycles lead, among others, to changing (increasing or decreasing) emissions in other sectors, which may be located inside or outside the city boundaries.

Table 12.X illustrates twelve intervention areas or urban mitigation opportunities (rows) and their potential impacts on emissions in different sectors (columns), within and outside the city's boundaries. The mitigation opportunities include interventions regarding urban form (1-6) and interventions in individual sectors (7-12). For the colour code (green – positive savings, red – negative savings), it is assumed that the city imports the vast majority of construction materials, fuels, electricity, and food from its hinterland. The list of mitigation opportunities is not complete, and it does not reflect the significant differences among cities with respect to geographical and socio-economic boundary conditions, including the state of the existing built environment stocks.

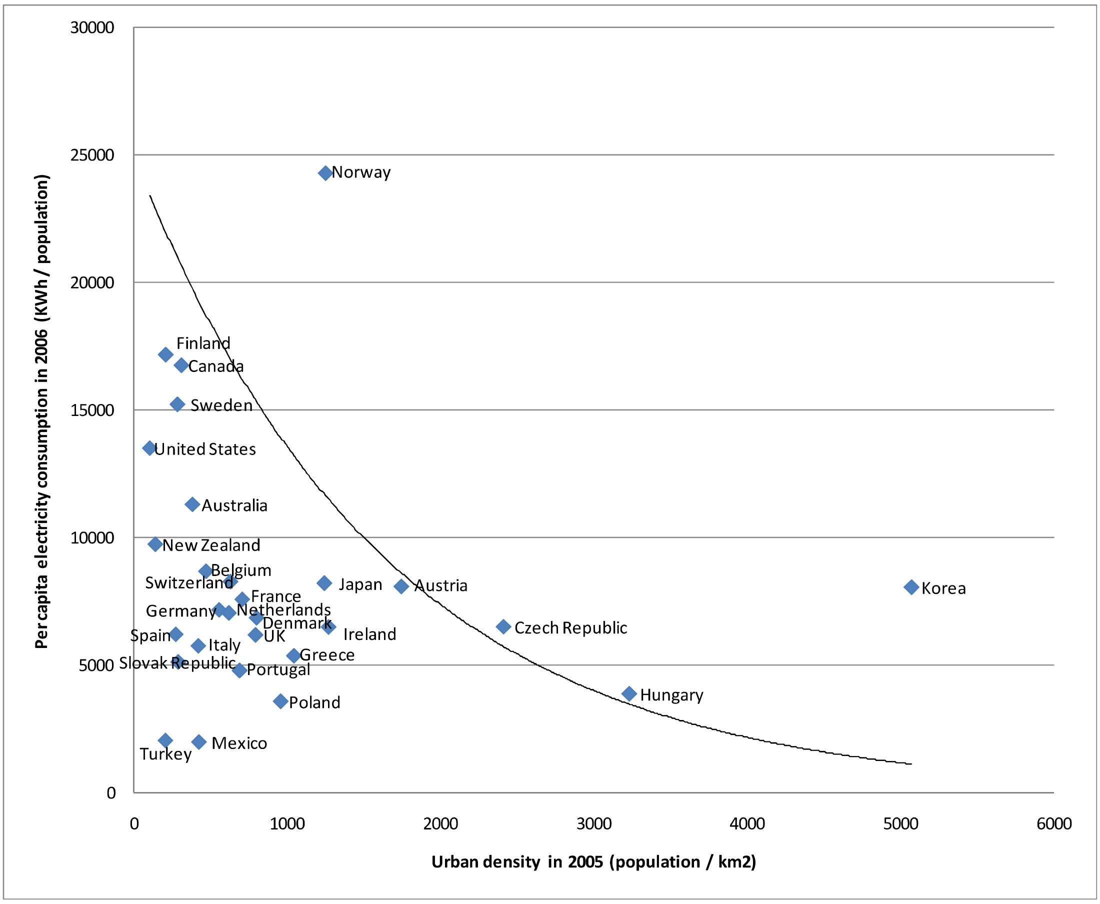
Table 12.1 Urban mitigation opportunities and their impacts on GHG emissions in different sectors within and outside the city's system boundaries. Assumptions are made for an average city that imports construction materials, fuels, electricity, and food from outside it borders.

Emissions	1 Transport		2 Buildings		3 Industry		4 Energy Supply		5 Agric / Forestry		6 Waste Mgt (incl. wastewater mgt)		Co-ben.	Risks
Drivers	- km travelled - transport mode - fuel efficiency - C intensity of fuel		- Floor area - Energy use per FA - C intensity of energy		- Materials demand - Recycling - Energy efficiency		- Transport fuel production - Building fuel production - Electricity production - C intensity of energy production		- Demand for wood - C sequestration in forests & buildings		- Urban mining / waste separation - CH4 landfills - CO2 Waste incineration - Energy per waste - CH4 and N2O wastewater treatm.			
Urban mitigation opport.	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside		
1. Compactness / density	Km trav T mode		Energy use FA			Mat.		T fuel			Urban mining			Urban heat islands
2. Devel around spines of public transport	T mode					Mat.		T fuel						
3. Polycentric structure	T mode					Mat.		T fuel						
4. Finer grain system	T mode							T fuel						
5. Land use mix	T mode							T fuel						
6. Urban greenscapes	T mode Km trav							T fuel	C seq.				Attractiv eness	
7. Low carbon buildings			Energy FA C seq.			Mat.		B fuel B electr I fuel I electr.						
8. Low carbon urban transport	T mode Fuel eff. C intens					Mat.		T fuel						
9. Low carbon energy supply			C intens			Mat.		B fuel B electr		Wood demand				
10. Water management					Water supply	Mat.								
11. Waste mgt (incl. urban mining)	Km trav.					Recycl.					CH4 landfills CH4, N2O WWT		Save res & waste	
12. Food consumption	Km trav.					Food process		Food proces s.		Animals Manure				

12.4.3.1 Compactness / density

Urban density and form (spatial organization) are key factors that influence energy consumption, especially in the transportation and building sectors (Kamal-Chaoui and Robert, 2009a, p. 21). The greater the compaction, the less aggregate amounts of vehicle movement (VMT) and the greater the propensity for walking, NMT and public transport. Sprawl also increases energy demand, aggregate amounts of infrastructure, and of waste collection, and increases costs. Increasing density tends to increase land use mix and transit accessibility while it reduces the average travel distances and increases the portion of destinations within walking and cycling distance (Newman and Kenworthy, 1996) (Wegener and Fuerst, 2004) (Lin and Yang, 2009) (Mitchell et al., 2011) (Dulal et al., 2011). However, there are trade-offs in terms of heat island effects and height (use of elevators). The result is that per capita vehicle travel tends to decline as well as GHG emissions (Cervero and Murakami, 2010) (Litman, 2012). The decrease of vehicles in terms of energy and material stocks and flows needed for a smaller fleet also contributes with diminishing direct and indirect GHG emissions and other environmental costs as a negative correlation seems to exist between population density and GHG emissions (1% of density increase produces a 0.7% of decline in carbon monoxide pollution at the city level if other factors held constant) (Litman, 2012, p. 17).

Data indicates that as density increases in urban areas, per capita electricity demand decreases (Figure 12.4). For instance Japan's urban areas are around five times denser than Canada's, and the consumption of electricity per capita in the former is around 40% that of the latter. Similarly, Denmark's urban areas are denser than Finland's by a factor of four and people there only consume around 40% of the electricity than the Finns (Kamal-Chaoui and Robert, 2009a, pp. 9–10).



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

Figure 12.4 Urban density and electricity consumption. Source: (Kamal-Chaoui and Robert, 2009a).

The impact of compactness/density on embedded emissions likely to be very large, however, there are few quantitate studies to support this hypothesis. In Australia, low-rise medium density houses were found to be less energy-intensive in construction than detached houses due to savings in shared walls, economies of scale, and surface area to volume ratio. However, for buildings higher than three storeys, the embedded energy per floor area rises due to exponentially increasing structural demands (Treloar et al., 2001; Rickwood et al., 2008). See section 12.3 for further discussion.

12.4.3.2 Development around spines of public transport

Tendencies towards linearity (expressed either in total settlement forms or as corridors of higher density development around spines of public transportation within larger settlements) lead to greater use of public transport and other private vehicles, as opposed to more concentric forms. For network structures, the connectivity or permeability becomes important – the more interconnected or permeable movement systems are, the less the probability of extensive congestion. Material demand and corresponding embedded emissions is likely to be lower compared to urban sprawl due to increased density. See section 12.3 for further discussion.

12.4.3.3 Polycentric structure

Generally, polycentric structures result in reduced aggregate amounts of movement. Material demand and corresponding embedded emissions is likely to be lower compared to urban sprawl due to increased density. See section 12.3 for further discussion.

12.4.3.4 Finer grain systems

Finer grain systems (characterized by smaller blocks which enable frequent changes in direction) promote walking. Impacts on material use and corresponding embedded emissions are still poorly understood. See section 12.3 for further discussion.

12.4.3.5 Land use mix

More mixed patterns tend to reduce aggregate amounts of movement and promote walking. See section 12.3 for further discussion.

12.4.3.6 Urban greenscapes

Green areas can make cities more attractive to live in (particularly important for promoting more dense cities) and may promote walking and bicycling. Urban greenscapes can provide biomass for building heating and thereby reduce the demand for fossil fuels, although this potential is usually very limited. The potential for carbon sequestration in green areas within cities is usually small and limited to the growth phase of the plants. Vegetation can reduce the reflection of sunlight and can play a role in reducing heat island effects – albedo effect.

Urban agriculture can generally represent only a small potential for both, climate mitigation and food self-sufficient of urban residents. Nonetheless, it can have several socio-ecological co-benefits such as promoting local leisure activity (may reduce recreation-related transport emissions), employment, and the reduction of negative urban nutrient footprints of cities by partially using urban excreta –which may slightly reduce GHG emission (Barles, 2007); (S. Barles, 2007) (De Zeeuw et al., 2011). Major opportunities have been identify for some urban settlements in Africa, Central America and the Caribbean where the role of (peri)urban agriculture can represent up to 40-60% of local needs of certain types of fresh products (Drechsel et al., 2007). See sections 12.3 and 12.8 for further discussion.

12.4.3.7 Low-carbon buildings

Residential and commercial buildings account for about 15.2% of global total GHG emissions (WRI 2011) or 33% of global energy and process related CO2 emissions (Allwood et al., 2010) (including direct emissions and emissions from electricity production associated with buildings, but excluding materials used to construct buildings). In addition, the building stock constitutes a mayor reservoir of materials and associated embedded GHG emissions, which is built up over decades or centuries (long lifetime). (Baccini and Bader, 1996) estimate the average material stock in buildings in industrialized countries to be about 110 t per capita. Energy embodied in materials is considered to be equivalent to 60% of life cycle heating demand in Spanish dwelling (Zabalza Bribián et al., 2009), while in a UK office building it could represent 67% of the operational energy demand over a 25 year period (Yohanis and Norton, 2002).

Cities, with their concentration of buildings face, both unique opportunities and trade-offs related to GHG emission reduction. Energy use in buildings depends on their orientation, compactness, and configuration (see Chapter 9 for details). Building improvements, enforced by building codes, can reduce heating energy requirements in new buildings by 90% or more, with large savings in space cooling. Deep retrofits of existing buildings offer large reductions in energy demand. Energy efficient equipment in buildings can further reduce energy consumption and associated emissions, including electronics, appliances, and equipment. Cities can influence the set of products manufactured by having procurement programs, and gain leverage by coordinating with other utilities and other multi-level jurisdictions on performance specifications. Controls and user behaviour provide a third complement, reducing the hours of usage of energy-using devices in buildings. Cities that operate utilities can influence energy usage directly by using smart meters and information infrastructures. Efficient use of water, water heat improvements, and reuse reduce energy use and emissions associated with water and wastewater treatment.

Operational emissions from the building stock depend on the climatic conditions, the indoor temperature, the floor area used for residential and commercial purposes, the building design, and the type of fuel used. Urban areas in warmer climate zones tend to have lower direct final consumption of fossil fuels, but higher electricity consumption needed for cooling. Larger houses occupy more land, require greater amounts of material for construction, and consume more energy heating and cooling. The per-capita floor area tends to grow with rising income as a consequence of declining occupancy and increasing dwelling size. In most industrialized countries, the average household size has stabilized around 2.1-2.2 people per dwelling. In many countries (including US and China), the average dwelling size in dense urban areas with high GDP is smaller than in rural areas or sprawling counties.

(Pauliuk et al.) developed energy scenarios for renovation and replacement of the Norwegian dwelling stock until 2050, considering direct and indirect energy use. They found that a renovation strategy could reduce overall energy use more effectively than a strategy of replacing the dwelling stock, provided that energy intensity of renovated buildings can be reduced to the same level as is possible with new buildings, due to the high energy use related to the replacement of the building stock compared to the energy use of renovation measures. However, a strategy of replacement may be favourable in cases where renovation measures are less effective.

12.4.3.8 Low-carbon urban transport

Transport generates assorted boundary conditions for social organization and for society-environment relations (Fischer-Kowalski et al., 2004, p. 307). It demands distinctive amounts of infrastructure and thus consumes varied amounts of materials and energy, particularly if centered on private transportation and if different public transport systems are not fully integrated, including the urban dimension of freight logistics. It usually figures as one of the largest assets of cities, covering a vast surface and thus comprising a major portion of urban systems' material stock. In motorized cities, it has been estimated that 30% of land is devoted to roads while up to another 20% is required for off-street parking (Rodrigue et al., 2009).

To reduce overall emissions most effectively, it is important to account for direct and indirect GHG emissions of diverse transportation modes over an extended time period. This means: those associated to the processing (mining or extraction) and transportation of construction materials, to the construction, operation, maintenance, and decommission and recycling of infrastructure; as well as those emitted for the fabrication, delivery, operation, disposal and recycling of vehicles (Chester, 2008; Chester and Arpad, 2009).

As urban population and cities grow, expanding conventional transport infrastructure has clearly become more expensive in both, economic and metabolic terms as much energy and materials, which have to be brought from even further destinations, are needed to build more sophisticated surface, underground and elevated infrastructure (Delgado, 2012a). Implications and costs may vary from city to city. For example, while most Chinese cities consume about two GJ of transport energy per person (direct consumption), in Atlanta such amount goes up to 103 GJ (Dulal et al., 2011). Data also shows that modern transport material and energy demand for US average cities (in terms of inflows and outflows of the system) is at around 10 ton/capita/yr of material-energy input; 6 ton/capita/yr of gas output; 1.6 ton/capita/yr of solid residues, and about 160+2 ton/capita of material stock (Brunner and Rechberger, 2004, p. 20).

Integrated spatial planning can take advantage of a metabolic approach to reduce direct and indirect emissions through shaping urban form, structure, and transport concurrently (see 12.5.1.)

An integral multi-scale approach is starting to be seen as a condition for addressing simultaneously a diversity of dimensions such as mobility, accessibility and affordability, but also urban and suburban livability; therefore, it has been suggested to develop metabolic metrics livability measures (Newman P.W.G., 1999) (Delgado, 2012b). Renovating costs towards more sustainable and climate ready urban settlements may be less expensive in the long run if reductions on material/energy and economic costs of maintaining and expanding continuously private transportation infrastructure within growing, sprawled and unplanned cities, are considered. Dense, mixed use settlements require shorter utility lines and lower maintenance and operating costs than single use, expansive urban areas.

The timescale over which such a change might be realized could be similar to the turnover of the material and embedded energy stock which has been estimated between 2 to 3% per year (Brand, 2006, p. 5) (Banister, 2011). Yet, decisions on the type and location of new infrastructure will have a major immediate effect, not only on travel patterns, but also on settlements metabolism and thus on environmental repercussions including GHG emissions. As such effects will impact over the lifetime of this or that infrastructure, planning future infrastructure is currently the most relevant issue (Davis et al., 2010, p. 1331).

12.4.3.9 Low-carbon energy supply

Municipal energy utilities can use efficient local electricity and heat generating plants and renewable energy sources such as solar and wind. Interlinking local renewable resources through a local grid may assist a city to become a power supplier (Vettorato et al., 2011). Integrated planning, including energy and water systems, provides additional mitigation potentials (Piguet et al., 2011). For example, Bataille et al. (2009) reported that an integrated community energy system could result in over 43% emission reductions in Vancouver. Hara et al. (2001) reported 11% of the CO2 reduction potential by introducing technologies such as the solar power generation systems on the residential roofs, the co-generation systems for commercial sectors, and an solid waste power generation system and the district cool/heat supply using sewage water by the heat pump, which were assumed to be used in 2km distance area from Sinagawa rail station in Tokyo. To use solar energy more efficiently, the rooftops in cities could be optimized for solar energy collectors and the building height and spacing could be optimized to maximize passive solar heating and cooling (Scartezzini et al., 2002). Despite many opportunities and scattered small-scale case studies, the share of energy that renewable sources can provide in large and dense cities are poorly understood and depends largely on the climatic and geographic conditions as well as the settlement structure.

In order to introduce renewable electricity and to reduce electricity consumption and utility peak in the cities, "Smart Grid" has caught attentions recently, which include not only the deployment of advanced communications, information, and sensor technologies throughout electricity infrastructures for two-way communications, processing and use of information, but also the participation in demand response programs (Willrich, 2009). Moreover, using plug-in electric vehicles as a storage system, 10 % generation with renewable sources at 95% efficiency by 2030 is estimated in Las Vegas, USA (Xu et al., 2011).

12.4.3.10 Water management

Urban water systems produce GHG emissions in the form of CO_2, CH_4 and N_2O. Open drains, polluted lakes and rivers, water storage in barrages/dams, and treatment methods in sewage treatment plants are the main sources of direct GHG emissions. In addition, water infrastructures are very material intensive and their construction therefore involves substantial indirect emissions (Venkatesh 2011). Direct energy use by water utilities varies by city, but it can be for some cases highly intensive as for instance in Mexico city, where 3.4 millions of oil barrels are burned yearly (De Buen Rodríguez, 2008, p. 10). Likewise, Australian water industry's GHG emissions have been related up to 76% to imported electricity use (Kenway et al., 2008). The energy estimates will be 2-4 times higher if we include (i) energy consumed by conveyance of water from distant surface water sources,

(ii) energy consumption by booster pumps at household level in water distribution systems in developing countries, (iii) energy demand of several decentralized waste water treatment plants in industries and institutions, (iv) energy demand of Common Effluent Treatment Plants; (v) energy consumption in forms other than electricity; (vi) 100% collection and treatment of wastewater in cities in developing countries; (vii) embodied energy of materials.

To address the mitigation potential of water management effectively, it is crucial to understand the linkages between water, energy, and carbon. Demand for both water and energy is rising fast, and both depend on each other in multiple ways. Water-energy-carbon linkages in cities are through mechanisms such as energy consumption for water pumping, treatment, distribution, heating; water consumption for thermo-electric energy production and others. The nexus is related to three key contemporary policy objectives, namely, climate change mitigation, energy security, and water security but its importance is currently under-recognized (PMSEIC, 2011; Rothausen and Conway, 2011). Little has being done to address the tension between water and energy: water resource constraints are holding back solutions for more energy and energy problems are hampering efforts to supply more clean water.

Access to clean water is critical in many cities of developing countries. The lack of adequate water distribution infrastructure is going against equitable access to water and causes increased energy demand in water supply: water supply through tankers has an energy intensity of 530 MWh/kL, which is high by any standard for water distribution.

The rising demand for water and water infrastructures causes an even faster growing energy demand and GHG emissions. The energy demand for water abstraction is increasing because surface water needs to be transported over longer distances or extracted from greater groundwater depth. In Delhi, about 47% of the total water is supplied from a distance of about 240 km through manmade canal systems needing materials for infrastructures and intermediate pumping, and about 13% of the water is abstracted from an average depth of 20m. In addition, energy demand for purification of domestic water is increasing due to unreliable water quality. The domestic desalination water market is growing very rapidly. Last but not least, water pipelines and sewer infrastructure requires a lot of energy- and emission-intensive materials.

Water usage in cities is typically lower than agriculture use, but its socio-economic importance is high and the embodied energy and emissions in water infrastructure are usually substantial (CEC, 2005; LBL, 2011). It is particularly important in regions where high population growth and urbanization have caused a water crisis, pitting the water use for urban activities against agricultural and environmental water needs.

12.4.3.11 Waste management

Waste generation is an integral part of human activity and it is found to be proportional to per capita energy consumption, GDP and material consumption (Kennedy, Pincetl, et al., 2011). While waste management in developed countries contributes usually a relatively small share of total GHG emission, it is generally more important in developing countries. Figure 1 gives predominant sources and sinks and estimates of GHG emissions from the waste management sector. In addition, material recovery and recycling from waste offers maximum benefit with regard to GHG savings. For example, in the US, recycling resulted in GHG emissions savings of 183 million Mt in 2006. Estimates for other regions vary widely, depending on the recycled material and downstream substitution in the use of the recycled material (Friedrich and Trois, 2011). Savings are higher in countries where coal is the predominant source of energy (such as India, China and South Africa) and involvement of informal sector in waste recycling.

There is uncertainty and variability in estimates which are attributable to differences in the definitions of waste streams, GHG accounting convention (Gentil et al., 2009), exclusion or inclusion of minor generators and waste collection (Friedrich and Trois, 2011], availability of quality data, and assumptions in estimation models (Eriksson and Bisaillon, 2011). Complexity further increases while considering waste mix (urban, industrial, and agricultural) (Lacoste and Chalmin, 2006). Other than technologies as a short-term mitigation measure, long-term strategies could be centered firstly on avoiding or reducing waste, for instance by decoupling waste generation from economic factors such as GDP (Mazzanti and Zoboli, 2008).

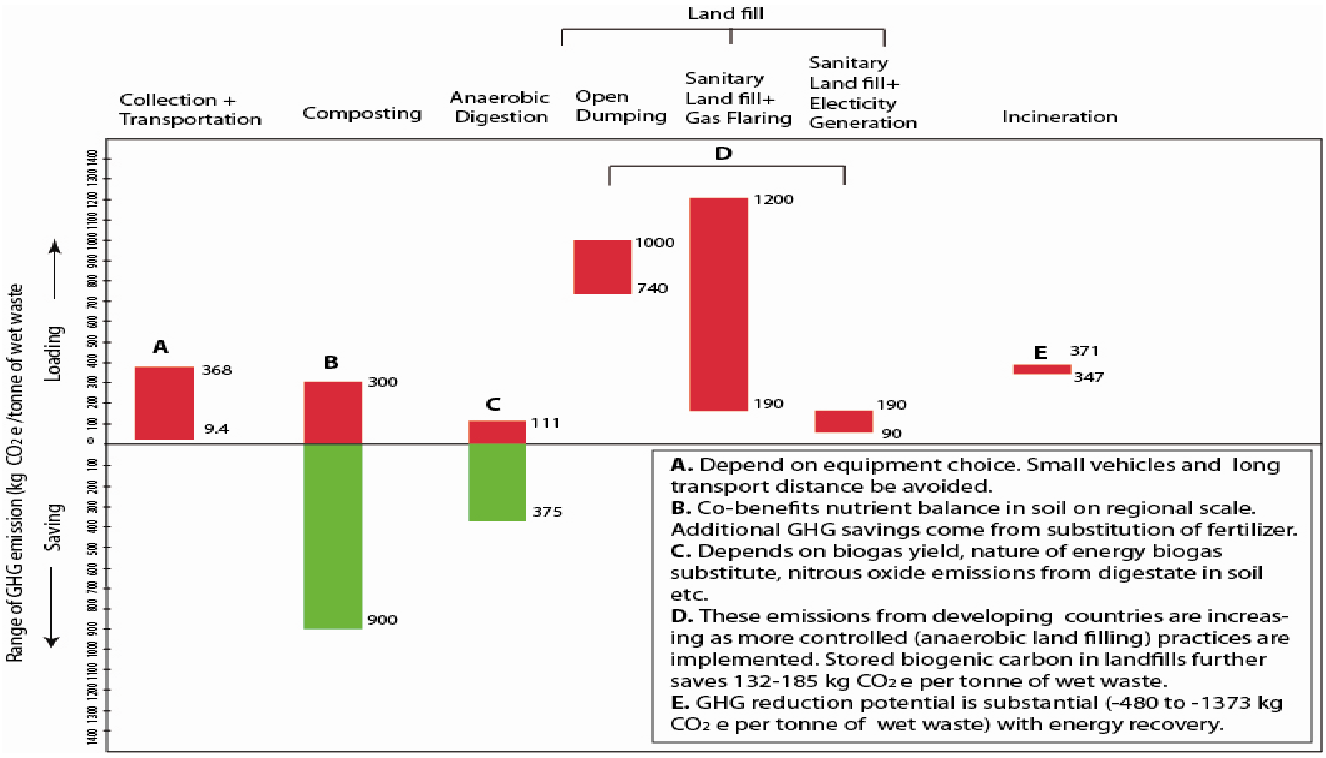


Figure 12.5 GHG emissions from waste management sector. Source: (Barton et al., 2008; Zhao et al., 2009; Astrup et al., 2009; Boldrin et al., 2009; Møller et al., 2009; Manfredi et al., 2009; Arribas et al., 2010; Friedrich and Trois, 2010)

12.4.3.12 Food consumption

About 14% of global GHG emissions are attributable to agriculture, and between 17-32% when considering land conversion effects (Pelletier and Tyedmers, 2010). Urban settlements typically include a small share of agricultural area, but still they largely depend on food imports from immediate rural hinterland and beyond. As generally urban diets have become more water and carbon intensive because of meat, dairy products and processed food consumption increases (D Pimentel and M Pimentel, 2003; Satterthwaite, et al., 2010, p. 2815; Theun Vellinga et al., 2010; M.M. Mekonnen and A.Y. Hoekstra, 2010), cities have become key drivers of GHG emissions associated to land change beyond cities' boundaries, even when considering disparities among low and high income regions (Galloway et al., 2007; Zaks et al., 2009; Gerbens-Leenes et al., 2010). While animal calories already represent up to a third of total available calories in developed regions, emerging economies, such as China, have increased such type of consumption up to five times from 1961 to 2007 leading a global demand for animal products that have already produced up to 50% of total land demand/change during that same period or time (Steinfeld and Gerber, 2010; Kastner et al., 2012).

By taking into account inputs, stocks and outputs of the whole food system, urban food metabolism comprises all subsystems of production, supply, distribution, consumption, social reproduction and generation/recycling of pollutants and waste (Delgado et al., 2010). Inflows and stocks cover land uses related aspects, production systems and practices, uses and misuses of water, fertilizers and other agrochemicals, the operation and maintenance of storage, food processing and packaging facilities, transportation, and indeed energy and other inputs and artifacts needed for preserving and cooking food by final consumers (DEFRA, 2008; Pimentel and Pimentel, 2008; Weber and Matthews, 2008; Heinberg and Bomford, 2009). Outflows include, besides non-used or wasted inputs, food wasted at the production processes (up to a third of total food production or about 1.3 billion tons annually: (Gustavsson et al., 2011) and at the household levels. Although inorganic residues –packaging- conforms the major remaining outflow, organic residues usually represent 30% to 40% of urban residues, depending on the city case, and contribute for most of the urban methane emissions (Bowman et al., 2000).

Though urban food emissions data are scarce, some soil nutrients and constrained food metabolic analyses have been carried out (Bohle, 1994; Barles, 2007). Preliminary indirect emissions (from "farm to table"), only of urban demand of meat, dairy and chicken eggs, have been estimated on 1.57 ton/h/year for Buenos Aires; 0.72 ton/h/year for Mexico City and 1.04 ton/h/year for Sao Paulo and Rio de Janeiro. Differences are mainly due to disparities on meat consumption (Delgado et al, 2012. In press)].

Supplying projected population by 2050 with current diet and agricultural technology of Northern America would mean that crop area would have to be doubled and with Western European standards it still will have to expand by 70% (Kastner et al., 2012). Even more, only GHG anthropogenic emissions from meat, milk and egg production by 2050, using FAO projections scenario (Pelletier and Tyedmers, 2010), have been expected to be 39% above of those reported in 2000, therefore in order to meet sustainability boundary conditions whilst maintaining year 2000 proportional contributions to total anthropogenic impacts for GHG emissions, biomass appropriation and nitrogen mobilization, it will be necessary to reduce in anticipated year 2050 per capita consumption of such products to the order of 19%, 42% and 21% of projected levels respectively (Ibid). However, such impacts could be lower if productivity is increase (Steinfeld and Gerber, 2010).

12.5 Spatial planning and climate change mitigation

Spatial planning is a holistic approach to guide spatial development and investment in infrastructure. It can include land use planning, urban planning, regional planning and environmental planning at different spatial scales. Spatial planning influences urban structure, form, and density (Wegener, 2001; Fischer-Kowalski et al., 2004; Yang et al., 2008; Hoornweg et al., 2011b). There is general agreement that spatial planning (or the lack therefore) can play an important role in reducing greenhouse gas emissions by influencing the structure, form, density, and infrastructure of a city (Carter and Fowler, 2008; Fields, 2009; Antrobus, 2011). This section assesses current knowledge on how spatial planning and resultant urban form can contribute to climate change mitigation (Ewing et al., 2008; Hodson and Marvin, 2009a; Antrobus, 2011). It focuses on three categories of spatial planning: plan formulation, planning outputs, and plan implementation (Campbell 2006; Lamm & Görling 1992; Storch & Downes 2011; Jia 2009; Vasey-Ellis 2009; O'Neill & Scott 2011; Walsh 1999; McDonnell et al. 2008a; Atkinson 2010)(Grazi and van den Bergh, 2008).

12.5.1 Integrated spatial planning

The underlying principle of integrated spatial planning is to coordinate land-use planning with other sectoral activities such as environmental policy, housing, and economic or regional development into a single framework (Eskelinen et al., 2000; Wong 2002). What differentiates an integrated spatial planning approach from individual sectoral approaches to climate change mitigation is that by coordinating multiple sectors, it is able to take advantage of solutions for a settlement as a whole that are not possible by individual sector policies alone. One estimate suggests that land-based mitigation is expected to contribute approximately 100 to 340 Gtc equivalents over the next century, or approximately 15-40% of total abatement (Rose et al., 2012). For example, urban transportation is a major emitter of GHGs in urban areas and compact urban form increased density can lead to GHG emission reductions by reducing travel distance for work and leisure (Grazi and van den Bergh, 2008). A reduction in motorized transport can be achieved without limiting mobility and accessibility. Integrated planning of land-use and transport can lead to an increased use of alternative modes of transportation (binomial relation density and a reduction-of-vehicle-ownership) due to other factors such as regional accessibility, land use mix, connectivity, and transport system diversity (Litman, 2012). In addition to changing travel patterns and the built environment, increasing accessibility through land use mix and connectivity rather than transport infrastructure alone can have a positive effect on health through reducing vehicle-based pollutants but also by the materials utilized (Younger et al., 2008). Co-benefits may thus include cleaner air, preservation/restoration of ecological services, and improvement of personal health (Frank et al., 2004; Brown, Khattak, et al., 2008; Rodrigue et al., 2009; Marshall et al., 2009; Hankey and Marshall, 2010). In addition, density and mixed land use can also reduce – to some degree – the amount of land needed and the energy and material flows and stocks required for building and maintaining roads, parking facilities and other related infrastructure. A low-carbon future can be achieved by spatial planning to promote new technologies to create new urban form (Crawford and French, 2008a). In contrast, a lack of integrated planning and a focus exclusively on infrastructure expansion can result in a decline in mobility with several unwanted societal impacts: while infrastructure has quadrupled over the last 50 years for some megacities of developing countries, mobility has fallen by up to 50% (Moavenzadeh and Markow, 2007).

12.5.2 Urban strategies for mitigation

Land tools have been utilized in cities to regulate use, type of development, densities and built up coverage at plot level. These regulations derive largely from statutory spatial plans and related regulations like the land laws. These regulatory land tools are partly responsible for failure of plans to address the needs of urban populations but also reduction of energy intense activities in cities. The opportunities for new and future cities is that climate change mitigation can frame the adapted regulation and possibly redefining the land tools to ensure low and or zero carbon cities.

The challenge with existing urban areas whether in global north or global south are diverse. In global north the challenge is to deal with the climate insensitive urban systems, housing, infrastructure and the case of sprawled cities the intensive energy use. For the global south cities, the challenge is to deal with new developments which may have implications on energy use while on the other hand the inherent development problems of existing infrastructure, housing and environmental infrastructure. Restructuring existing cities in global north will consider a wide range of options including further gentrification in cities for optimal space utilization, retrofitting urban infrastructure and housing with climate sensitive fittings, low carbon climate proofing and innovative green technologies (Ghosh and Head, 2009). For cities in the global south, restructuring can also consider a range of options from social upgrading, off the grid infrastructure systems, decentralized infrastructure provision, reconstruction with minimal destruction, public policy reform and assessment of economic opportunities that could spur growth while ensuring environmental sustainability.

12.5.3 Implementation instruments

Urban planning and its implementation tools, both regulatory and market-oriented can help to reduce carbon emissions in several sectors. For example, land use regulations can facilitate appropriate densities for efficient transit, or mixed uses to increase pedestrian or bicycle trips; or building codes can require greater energy efficiency in heating, cooling and electricity use. Urban planning institutions have developed a range of implementation tools, regulatory and market-oriented, to carry out urban development plans. Table 1 provides a description of implementation tools, identifies their relevance to climate change mitigation, as well as the limitations of the tools.

These local tools for the implementation of spatial planning vary in their effectiveness even within high- income countries (Blanco, H. et al., 2011).

In low and moderate-income countries where planning and urban management institutions are missing or deficient, urban climate change mitigation efforts may require institution building or other approaches that rely on regional or civil society efforts. Traditional land use regulations, especially zoning, have been criticized, for their inflexibility, and for how they segregate land uses, which, with the increase in automobile ownership has resulted in increased vehicle miles traveled, more automobile trips, greater gasoline use, and thereby greater carbon emissions. However, over the past decades, land use regulations in developed countries have adopted more flexible approaches, such as density bonuses that capture value-added by land regulations for public goods (Feiock et al., 2008), or transfer of development rights from rural to urban areas that use quasi-markets to compensate landowners in rural areas whose property use is restricted by regulations (Henger and Bizer, 2010). Metropolitan regulations to manage urban growth or sprawl, such as urban greenbelts or urban growth boundaries are instruments that can reduce carbon emissions by preserving vegetation carbon sinks. Traditional, value-capture, and metropolitan approaches to land regulations offer promising opportunities to reduce energy use within urban areas and their associated carbon emissions, as well as to preserve green areas that serve as carbon sinks.

Table 12.2 Planning-Based Tools for Climate Change Mitigation

Implementation Tool	Description	Geographic Focus	Potential Relevance for Climate Change Mitigation	Limitations of Tool for Climate Change Mitigation
Traditional Land Use Regulations				
Prescriptive Zoning	Separates zones for different land uses(residential, commercial, industrial), sets maximum densities for each zone, height and setbacks, on-site parking requirements. Provides owners with predictable rights. (Lerable 1995)	Urban Areas	Density and land uses are drivers of travel patterns; High densities and mixed uses can increase transit use and non-motorized travel Basis for incentive zoning	Requires changes in zoning to increase existing zoning densities—may be politically difficult; Time lag between zoning changes and changes in urban form and travel patterns
Subdivision Regulations	Subdivides land into parcels, primarily for residential uses; sets standards for streets and public facilities provision, e.g., amount of parkland needed, stormwater system (Freilich and Schultz 1995)	Rural and suburban areas	Amount of open space required by subdivisions could be important for retaining green carbon sinks in suburbanizing areas	Primarily effective in countries with strong planning institutions
Flexible Zoning Techniques				
Mixed Use Zones	A type of zone that allows the mixing of specific uses, e.g., residential and commercial (Grant 2002; Coupland 1997)	Urban Areas	Mixed use areas, especially dense areas, are likely to shorten auto trips and encourage pedestrian and bicycle trips	Requires change in zoning—likely not as politically difficult as increasing zoning density
Overlay Zones	A second layer of regulation imposed on underlying zoning to allow, e.g., mixed uses, or design standards in specific areas	Urban areas	Can be used to create districts with lower on-site parking requirements;	Easier to create an overlay district than to change zoning
Incentive or Market-oriented Techniques				
Density Bonuses	A technique whereby a municipality designates certain zoning districts, typically in downtowns, where developers can obtain greater density (density bonuses) than allowed by existing zoning in exchange for specific public goods or services (Getzels et al. 1988; Morris 2000)	Urban areas	Density bonuses could be provided for energy efficiency in buildings	May compete with other public purposes, such as affordable housing

Land Re-adjustment	A process whereby landowners in an area to be redeveloped have a choice of either selling their land to the city or share in the development rights of the new project area. The technique reduces the public cost of purchasing private property for redevelopment, and can provide a profit for landowners. (van der Veen et al., 2010)	Redevelop-ment areas	Public financing of redevelopment can be reduced, and yet public purposes, such as greater energy efficiency, could be achieved with this technique.	Transaction costs are likely high
Design-Oriented Codes TND, Transect Zoning or SmartCode, TOD, Urban Village	Design codes or plans based on new urbanist principles that provide building typologies and design guidelines for town-scale development, with some mixed uses, public spaces, pedestrian scale. In its most recently developed concept, *transect zoning*, zones and building typologies range from the countryside to the city. Smart growth combines elements of the new urbanism and urban growth management techniques. (Duany and Plater-Zyberk 1991; Calthorpe 1993; Bernick, M. and R. Cervero 1996; Duany and Talen 2002; APA 1998; Downs 2001;)	Suburban or Urbanizing Areas	The higher densities, mixed use, pedestrian and transit orientation of design-oriented codes could shorten and reduce auto trips, and increase pedestrian and bicycle trips. Transect zoning includes rural zones that could preserve green carbon sinks.	Easier to apply to undeveloped areas; in existing urban areas, would face the problem of changing land use regulations
Urban Growth Management Tools				
Greenbelts	In the UK, designation in local development plans of large belts of rural lands surrounding an urban or metropolitan area to prevent urban sprawl and provide open space. Development within the greenbelts is restricted to rural and related uses. (UK Department of Communities and Local Governments 2001).	Metropolitan areas	Preserves green carbon sinks	Could increase the size of metropolitan areas by pushing some population to move beyond the greenbelt, thereby increasing the length of a portion of commute trips
Urban Growth Boundaries	Metropolitan growth management boundaries to demarcate land intended for future urban development and rural land to	Metropolitan areas	Preserves agricultural and resource lands and, in general, reduces the pace of land conversion to urban uses	Requires strong metropolitan planning and infrastructure provision

	be protected from urbanization. In Oregon, USA, the land within the boundary is required to contain a supply of land to accomodate twenty-year growth projections. The land outside the boundary is to be protected from urban development. Land within the boundary is to be supplied with urban-scale public infrastructure, while land outside the boundary is not. (Easley 1992; Nelson and Dawkins 2004)			powers and institutions; Increases housing costs within the boundary, and thus requires associated strong affordable housing policies
Adequate Facilities	Regulations, beyond zoning, requiring that proposed development have adequate urban facilities, such as water and sewer, roads, parks, fire services before obtaining development permits. Unlike zoning, these regulations can help localities time and sequence urban development. . (Freilich and Schultz 1995; Freilich, Sitkowski, Mennillo 2010)	Suburban areas	Regulations reduce the rate of land conversion to urban uses until development can be adequately serviced.	
Agricultural/Forest Zoning	Regulations that do not permit any development other than agricultural or forest services in such zones. (Nelson 1992).	Suburban areas	Regulations preserve green carbon sinks	Politically difficult to maintain, especially in urbanizing areas.
Transfer of Development Rights	Regulations that allow the transfer of development rights from agricultural or forested areas (sending areas), where urban development is restricted, to urban areas (receiving areas), where higher densities are encouraged. Transfers could be facilitated by a TDR bank. (Roddewig and Inghram 1987; Henger and Bizer 2010).	Rural and urban areas	Programs preserve green carbon sinks and increase densities in urban areas.	TDRs work when there is strong demand for higher density than permitted by existing zoning in the receiving area
Land dedications or Fees-in-Lieu	Regulations that require developers to provide land to local governments for streets, parks, schools, etc. (Mandelker 2003).	Suburban areas	Land dedications can be used to preserve green carbon sinks	Land dedications would be limited to the open space requirements for each subdivision.

Development or Impact Fees	Regulations that require developers to pay a fee based on the amount of development planned to cover part or all of the costs of the infrastructure needed by the new development (Bowyer 1993)	Suburban areas	Impact fees could contribute to energy efficiency within the development, or reduce carbon emissions in other ways	Would require a connection between the fee and the impacts of the development

12.5.4 Barriers and opportunities

Although it maybe still unclear how spatial planning is perceived by national government in the climate change debate, spatial planning can assist in the implementation of financial, institutional and technical means to mitigate climate change (Biesbroek et al., 2009). However, the function of spatial planning to coordinate among different sectors for mitigating climate change is not without limitations. Each sector formulates their own strategies according to their own objectives. An integrated approach for mitigating climate change is no simple process of coordination among different agencies; it's a pragmatic solution that can only be found from local planning efforts. The implementation of mitigations strategies are usually a top-down process. Local mitigation strategies generally are instructed by the regional or national policies, which again are directed by international agreements (i.e. UNFCCC, Kyoto protocol) for reducing GHG emissions.

The effectiveness of urban planning and its implementation tools, whether regulatory or market-oriented, depends on the sophistication and flexibility of the land market and its institutional context. Because of the dissimilarity of land markets across regions and contexts, the real estate sector may be a suitable platform for implementing market-based mechanism in carbon mitigation. Given the significant contribution of greenhouse gas emission from the real estate sector, a blend of mandatory government regulation and voluntary industry standards has emerged in response to pressure. The real estate industry has a valuable opportunity to monetize emission reductions while simultaneously reducing operating expenses and modernizing their property portfolios (Binkley and Ciochetti, 2010). Although "green markets" have expanded dramatically in some sectors of the economy in response to price signals, there is little empirical evidence that commercial real estate prices are influenced by their sustainability characteristics despite widely propagated financial and environmental benefits (Fuerst and McAllister, 2011). Market-based land policies aiming at compact urbanization are likely to be effective tools in emission mitigation. The development of "compact centers" with relatively high density can result in improved environmental quality and less carbon emission in most countries due to lower land consumption (Mehaffey et al., 2008).

12.6 Governance, institutions, and finance

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

12.6.1 The role of civil society organizations

Civil society organizations assist climate change mitigation through shaping public opinion, through their own actions, as well as by exerting pressure on the other stakeholders to act. They also enable the participation of citizens, which is often crucial for the success of mitigation initiatives.

Civil society organizations can play a key role in shaping public opinion on the impacts of climate change, influencing the decisions of local governments, and campaigning for the widespread adoption of mitigation strategies (Tanner et al., 2009). A diverse array of civil society organization, including research institutions, advocacy groups, community groups, religious institutions, self-help groups and labour groups, have begun to collaborate, with their belief systems influencing the directions in which they seek to set policy agendas and shape public opinion (Bulkeley and Moser, 2007; Moser, 2007).

Activist groups motivate greater public involvement in mitigation, helping to combat public feelings of powerlessness and hopelessness (Moser, 2007). NGOs also play an important role as watchdogs, providing independent scrutiny of the funding and function of government, corporate and donor agencies (Robinson et al., 2006; Newell, 2008; Revi, 2008). For instance, civil society groups have helped to pass corporate shareholder resolutions demanding information disclosure on climate change impacts and mitigation strategies (Newell, 2008). Civic groups have played an influential role in policy change through initiating judicial interventions (Moser, 2007; D'Souza and Nagendra, 2011). Finally, civil society groups can be particularly useful in focusing the attention of governments and donors towards ignored vulnerable urban groups (Newell, 2008; Douglas et al., 2008; Hardoy and Pandiella, 2009). However, imperatives of funding can sometimes compel civil society actors to conform to government developmental priorities (Ayers, 2009).

12.6.1.1 Citizen participation and grass-root initiatives

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

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

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

12.6.2 Role of governments and cross-city networks in urban mitigation

12.6.2.1 National, provincial, and municipal services

The roles of various levels of governments in climate change mitigation in cities vary in different city settings. These roles are primarily determined by the state of decentralization of the government power structure and are also linked to their government's resources and their capacity to influence mitigation activities. While the responsibility for mitigation mainly lies with municipal governments, States may regulate energy production and promote incentives for carbon emission reduction via pricing and other measures. For instance, California in 2006 passed its Global Warming Solutions Act, enforceable legislation to curb GHG emission to the 1990 level by 2020; ten north-eastern and mid-Atlantic States in the U.S. have created the Regional Greenhouse Gas Initiative, a marked-based program to cap emissions from the power sector by 10 % by 2018 (UN Habitat, 2011).

Municipal Governments can govern climate change mitigation in four ways: by self-governing (i.e reducing GHG from their own municipal activities), by legislating, by provisioning and by enabling (Alber and Kristine, 2011). The rising interest among local governments to assume more responsibility to mitigate city emissions is a positive trend for climate - mitigation. Nevertheless, the literature and the municipal-centric policy debates often fail to take into account the limited ability of municipal governments to influence substantial amounts of emissions from urban activities because of several structural factors in cities, such as limited municipal mandates in shaping urban investments, the provision of municipal utility services by the private sector, limited authority, crumbling financial performance, etc (Dhakal, 2010a). Local government initiatives are more likely to succeed and have impact when they rely on the involvement of other local actors (communities, private sector), as well as on a favourable national policy environment which provides resources and incentives related to GHG reduction targets (OECD 2010) . Multi-layered institutional arrangements of metropolitan governance plays an important role in shaping city mitigation strategies; thus, the role of municipal government is central and absolutely necessary but often not sufficient, especially in less developed and emerging countries (Dhakal, 2010a). National governance shapes the potential and the incentives of municipal governance. In New Delhi, the city's climate action plan is a replica of the national action plan (ASSAF, 2011). In China, local leaders often implement the policy directives of the higher-level governments rather than making their own (Yang et al., 2008; Dhakal, 2009). In China, mayors are subject to an incentive scheme within the Communist Party, e.g. rewarding urban economic growth (Li and Zhou, 2005). Chinese municipal revenue generation, as framed in national legislation, is often focused on land development, incentivizing rapid but mostly unplanned construction work not well integrated into a public transport system (Creutzig, 2012).

12.6.2.2 Municipal associations and broader networks

In the past two decades, urban GHG mitigation has been increasingly supported by national and international municipal organizations, and some new ones have been emerging, such as the United States Mayors Climate Protection Agreement (Warden, 2011). ICLEI, an NGO with membership of over 1,200 municipalities, assists city governments with mitigation strategies. The C40 association (established in 2005), and originally representing the 40 largest cities in the world of which half are in the industrialized countries, provides assistance to its members to reduce urban carbon emissions, often in partnership with foundations and the private sector. The Mayors Council on Climate Change (established 2009) regroups over 50 cities worldwide committed to a set of climate-related and environmental actions, including the recording, certification and tracking over time of their levels of carbon emissions. The European Union Covenant of Mayors (established in 2008) has been endorsed by over 2,900 municipalities, over 700 of which have already prepared Sustainable Energy Action Plans, which aim to achieve or surpass locally the EU-wide objective of 20% emissions reduction by 2020 against the 1990 baseline.

Municipal governments in emerging economies and developing countries find support for their mitigation strategies and for the design of climate action plans from municipal networks and international agencies. Organization such as UN-HABITAT, UNEP and the World Bank provide support to municipal governments through various mechanisms, the focus of which has been awareness programs and technical assistance. They have also collaborated in the joint effort of ICLEI, C40 and WRI (World Resources Institute) which launched in 2012 the Global Protocol for Community-scale GHG emissions, an inventory tool aimed at facilitating the collection of comparable data as baseline for urban mitigation (GHGPROTOCOL.ORG, 2012). The Clinton Climate Initiative's Cities Program provides project management, financial and purchasing advice and measurement tools (Rezessy and Bertoldi, 2010). These efforts often help unlock cities' energy efficiency potential and structure and implement projects such as retrofitting of public and private buildings, construction of sustainable buildings, energy efficient district heating and cooling systems, and environmentally friendly transport, thus helping cities attract finance from banks and other sources.

12.6.3 Private sector initiatives

12.6.3.1 Corporate initiatives and climate change mitigation

An increasing number of global private corporations are taking part in international initiatives which promote urban mitigation, whether pursuing objectives of sustainability, of corporate responsibility, or the promotion of environmental business opportunities and market share. Their activities range from introducing innovations in urban systems and systems management to improve the overall efficiency and livability of cities via greater use of information and technologies (for instance IBM, CISCO, Google, Philips etc.), to the design of sustainable and green, low-carbon neighbourhoods and cities (for instance ARUP), to studying the financial needs and investment opportunities to de-carbonize urban economies (for instance McKinsey, HSBC). Such activities are carried out in consultation or partnership with city governments and at times in association with municipal networks. Private sector support is also of relevance in the development of city green-house measurement methodologies.

12.6.3.2 Private sector networks and their activities

There are several private sector networks promoting a climate change mitigation agenda with direct and indirect links to cities. The World Business Council for Sustainable Development, a global association of some 200 companies, has energy and climate as one of their four focus areas, and its sector projects include studies and knowledge-sharing initiatives on water, buildings, cement production and urban mobility, promoting energy efficiency and emissions reduction (WBCSD, 2011). These elements have several implicit links to the cities. Another global forum, The World Economic Forum, addresses climate change as one of the key themes of its environmental sustainability agenda (WEF, 2011) . The Climate Group, established in 2004, as a non-profit organization created by about 100 global corporations and sub-national governments has city partnerships including Chicago and Mumbai, where it is collaborating with local governments to deploy energy efficiency programs and low-carbon technologies (Climate Group, 2011).

12.6.4 Financing urban mitigation

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 by requirements to meet certain carbon mitigation standards (OECD 2010). As decentralization has progressed worldwide (the average share of sub-national expenditure in OECD countries reached 33 percent in 2005), regional and local governments increasingly manage significant resources. Urban infrastructure investment financing comes from a variety of sources, including direct central government budgetary investments, intergovernmental transfers to city and provincial governments, revenues raised by city and provincial governments, the private sector or public-private partnerships, resources drawn from the capital markets via municipal bonds or financial intermediaries, risk management instruments, and carbon financing. Such sources provide opportunities for urban GHG mitigation initiatives (OECD 2010) but access to these financial resources varies from one place to another.

12.6.4.1 Fiscal and market-based instruments for urban mitigation

Land-use could affect carbon emissions through urban form, and property taxes affect land use. Property taxes could be favouring single family houses discouraging compact city development, as in the USA, where cities and States tax apartments more heavily than the single family homes, considering them commercial real-estate (Goodman, 2006). Elsewhere, as in Greater Copenhagen, the inverse is true, where housing cooperatives are not subject to the municipal property tax (H. Andersen 2007) (Skatteministeriet, 2008). More compact development can be stimulated by introducing split-rate property taxes, as in Sydney, Hong Kong, Pittsburgh and Harrisburg, and other cities in Denmark and Finland, where land value is taxed more heavily than the buildings on the land, thereby providing an incentive to densify. Many cities depend on land sales for a large part of their revenues, which can create perverse incentives for urban sprawl. In the case of China, local governments have been so motivated to generate revenues from land sales and leasing that they have generated an oversupply of land for construction, which in turn has stimulated sprawled development (OECD, 2011).

Metropolitan or municipal transportation policies and taxes affect urban carbon emissions. Congestion charges have been observed to reduce GHG emissions from transport up to 19.5 % in London, where proceeds are used to finance public transport, thus combining global and local benefits very effectively (Beevers and Carslaw, 2005). Parking charges have led to a 12% decrease of vehicle miles of commuters in US cities, a 20% reduction in single car trips in Ottawa and a 38% increase of carpooling in Portland (OECD, 2011). In some metropolitan regions, transportation-related taxes are used to fund mass transit systems, by applying value capture taxes to the increase in property values arising from public infrastructure development, as in Singapore, Hong Kong, Milan, and Bogotá. In the Paris metropolitan region, companies employing nine or more employees are subject to a surcharge of salary rates of up to 2.2 %, which is a corporate contribution to public transit and provides around 70 % of the revenues of the metropolitan transport authority (OECD 2010).

12.6.4.2 Financial resources for urban mitigation in industrialized countries

Some G20 countries, and in particular those of the European Union, have made significant mitigation commitments. For 2007-2013, EU funding for energy efficiency, co-generation and energy management totals over 4 billion Euros. In addition, the EU-financed 450 operational programs include investing 9 billion for energy related projects and nearly 5 billion for renewable energies. The JESSICA program (Joint European Support for Sustainable Investment in City Areas) currently has commitments of over 1 billion Euros with member states and regions. In Lithuania, the program will invest over 220 million Euros in energy efficiency projects for retrofitting multi-apartment buildings via loans to home-owners, co-financed nationally. In London, JESSICA funds are being applied to investments in environmental infrastructure for areas of intensification and urban regeneration (Rezessy and Bertoldi, 2010).

In many countries with no clear carbon emission reduction targets at the national level, such as the US and Canada, there are however commitments by States, Provinces and Municipalities to encourage carbon emissions abatement. In the City of Portland, under the Clean Energy World Program, single-family residential home-owners can receive 100 percent financing to implement a wide range of energy efficiency measures. Loans are provided at attractive levels of fixed interest rates and amortized over a 20-year period. Customers repay through their regular utility bill. Other utility companies in

California, Connecticut, Rhode Island and Massachusetts have been offering similar schemes for many years (Rezessy and Bertoldi, 2010).

Tokyo is world's first city to implement a Cap-and-Trade Program for reducing CO2 emissions. Started in April 2010, it mostly covers the CO2 emissions from energy use in large scale businesses and buildings of commercial and industrial sectors. About 1,400 such facilities come under the cap that account for about 20% of total CO2 emissions in Tokyo or 13 million tons CO2 (TMG, 2010).

12.6.4.3 Financing urban mitigation in emerging economies

Emerging economies are making commitments and investments in emissions reduction. China had a target of reducing energy intensity of economy by 20% in 11th Five Year Plans (2006-2010) and is mandating deeper targets in its 12th Five Year Plan (2011-2015) for CO2, setting targets to reduce energy intensity by 16% by 2015. China's national energy targets are often downscaled for implementation to the lower tier governments including cities (Dhakal and Poruschi, 2010). In 2008 India introduced its first National Action Plan on Climate Change, which includes the objective of dramatically increasing the use of solar energy and enhance energy efficiency, including within the context of urban areas. The Plan aims to make habitat sustainable through improvements in energy efficiency in buildings, management of solid waste, and modal shift to public transport. Mexico's Climate Change Program aspires to reduce carbon dioxide equivalent emissions by seven million tons from the 2008-2012 period (Anon 2008). Indonesia has announced a target to reduce GHG emissions by 26% by 2020 from business-as-usual levels. With existing commitments and plans, a massive amount of financial resources in these countries will be invested in cities aimed at climate change mitigation or urban development.

12.6.4.4 Financing urban mitigation in developing countries

Developing countries outside the G20, which collectively account for only 10 per cent of global GNP, have lower emissions levels, fewer available financial resources, and look at international sources of financing for mitigation. Bilateral aid flows to support emissions abatement are monitored by the Development Assistance Committee (DAC) using the "Rio marker on climate change mitigation". The latest available figures show that in 2008-2009 DAC members provided over $9 billion to developing countries for mitigation projects. Typical projects relevant to urban areas include waste management, sewage treatment, renewable energy, energy efficiency demand-side energy management, preparation of GHG inventories, and capacity building (OECD-DAC, 2011).

The UNFCCC (United Nations Framework Convention on Climate Change) provides resources to developing countries for carbon emissions reduction via the CDM (Clean Development Mechanism) and the JI (Joint Implementation) programs, but urban usage of these instruments has been marginal so far. Of the more than 2,000 CDM projects registered as of March 2010, only a limited number have been urban projects, mostly targeting landfill gas or waste water treatment, and there have been only two urban transportation projects. A similar marginal number of CDM projects (0.57 %) and certified emissions reduction by 2012 (0.16%) deal with energy efficiency in the urban building sector (OECD 2010). For cities in developing countries, greater opportunities are related to supplementing urban infrastructure financing with mitigation actions supported by the carbon market. Cities are also attracted to building energy retrofitting and waste and transport related CDM projects.

The Global Environment Facility (GEF), a multilateral financial mechanisms established in 1991, is the largest source of grant and concessional financing for mitigation. Up until 2009, the GEF has invested $2.7billion to support climate change mitigation projects in developing countries and economies in transition, of which $1billion was invested in 2007-2009. This funding has leveraged another $17.2

billion in project co-financing and helped avoid more than 1 billion tons of GHG, an amount equivalent to nearly 5 per cent of annual human emissions. Among its strategic programs, energy efficiency in buildings and appliances is of relevance for cities (World Bank 2011b). The Clean Technology Fund (CTF), a collaborative effort of donor countries and Multilateral Development Banks (MDB) to scale up the amount of accessible financing for climate change, approved an investment plan for Thailand which includes $70 million to co-finance a bus rapid transit system for Bangkok. The CTF is contributing to support the Metropolitan Administration's target of reducing emissions by 15 % (World Bank 2011a).

Multilateral Development Banks (MDB) have been increasingly contributing to climate change mitigation financing, with investments which trebled from $5.4billion in 2006 to $17 billion in 2009, accompanied by increased advisory and policy services, and leveraging additional financing for a total cost of projects and programs estimated at over $55 billion. Of this, the amount of funding that can support cities is not known but there is potential for funding urban mitigation efforts, for example, in the areas of urban transportation, or energy efficiency in buildings (United Nations, 2010b).

12.6.5 Barriers and opportunities for the governance and financing of urban mitigation

Cities around the world are leading efforts in climate mitigation. Often pushed by civil society organizations and pulled by municipal associations, as well as broader networks and initiatives, many cities have undertaken ambitious plans, especially in industrialized countries, to reduce GHG emissions. Most of these plans primarily focus on energy conservation measures in the built environment and transportation sectors (Bulkeley and Kern, 2006). However, many of the cities that prepare ambitious mitigation targets fail to pursue them systematically, and implementation is mainly focused on municipal government operations, which account for a small fraction of total city emissions (Bulkeley, et al. 2012, 127). From a governance perspective, cities face major barriers in their mitigation efforts; some of the key ones are: spatial mismatch between the nature of the problem and the jurisdictional boundary of cities; temporal mismatch (long term nature of the action vs. political cycle); and a lack of jurisdiction and institutional capacity (Dhakal, 2008). The problems of scale and readiness are intricately linked to the several aspects of governance, which vary greatly among cities (Bai 2007)(Dhakal, 2008, p.184). The ability of the local governments to obtain resources and their legislative power to devise plans and enforce them are crucial factors for carbon governance, of great importance, especially for cities in developing countries. However, even in cities as such as New York and London, the jurisdiction of mayors is limited by many structural factors.

Strong political leadership is a key for city climate governance as seen from the cases of Bogota, Mexico City, Malmo, Tokyo, Chicago, London and New York. However, this is not a necessary condition, especially in developing country cities, where international donors, local academic and civil society groups can play a similar catalyzing role (Roberts, 2008; Roberto, 2009; Dhakal, 2010a).

Since national, and, to some extent, provincial governments control the overall policy environment, city efforts are constrained to mitigation strategies they control, such as energy efficiency measures in government services, or local land use planning. Mitigation strategies, such as carbon reducing fuel efficiency standards or cap and trade policies (such as in Tokyo), which primarily affect, or are implemented in urban areas, require at least provincial, if not national supportive policies. Efficient land use-transportation patterns in urban agglomerations require metropolitan planning which often crosses administrative boundaries, and requires an inter-municipal coordination system (McCarney and Stren 2009)(McCarney and Stren, 2008).

In countries lacking provincial or national policies on climate change mitigation, existing voluntary efforts are subject to uncertainties. Without national and provincial frameworks for policy, legislation, or financing, city efforts in mitigation will remain voluntary, subject to resistance, reaching only a small percentage of cities, and likely carried out mainly by higher income cities. In times of economic recession, budget cut-backs affect climate change mitigation efforts. In the U.S., for example, the House of Representatives 2012 budget slashed funding for domestic and international climate change programs (Lefton,, 2011).

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). In order to be effective, climate change mitigation policies will require long-term to centennial scales of consistent implementation (Hesselman et al. 2003). This conflicts with short-term election cycles, especially at the local level, where electoral politics rewards quick wins. The institutional capacity of local governments for undertaking climate change mitigation planning varies even in developed countries. In developing countries, institutional capacity is often deficient. In South Africa, for example, a recent study of climate change efforts indicates that while metropolitan municipalities such as eThekwini or Johannesburg had formulated climate change and energy efficiency strategies, smaller and poorer municipalities faced fundamental challenges—how to deliver effective services to communities (Richards, 2008).

During economic recessions, budget cuts can threaten investment in climate change mitigation, however, the other major strategy to deal with recessions, stimulus funding, presents a prime opportunity for investing in mitigation. OECD, in particular, has promoted a policy of a green stimulus, i.e. investment in energy efficiency, renewable energy, and other climate change or sustainability strategies (OECD, 2009). According to a World Bank report (Strands and Toman, 2010), in 2009, green programs in stimulus packages in high income countries and in China and South Korea amounted to 15% of total stimulus funds, varying by country, with South Korea's green programs amounting to the largest share, and China's to the largest amount. In 2011, the World Bank entered into a partnership with the C40 cities to lend directly to these cities for climate change mitigation plans (Peirce, 2011).

Research on the climate mitigation efforts of cities suggests that issue framing is a critical driver for climate policy and action (Bulkeley et al. 2012, 150). Many cities with active climate programs have framed such programs in terms of "energy security, efficiency and fuel poverty"; and transportation strategies in city climate action plans are often framed in terms of their air quality, congestion and health benefits. This suggests another opportunity for expanding urban mitigation programs. By communicating the co-benefits of climate strategies in terms of energy efficiencies or air quality improvements, cities can garner greater public support for climate mitigation efforts.

12.7 Urban climate change mitigation: experiences and opportunities

Since the IPCC 4th Assessment Report, hundreds of cities around the world have implemented or are developing climate change mitigation plans. This section assesses urban climate change mitigation experiences and their effectiveness in reducing GHG emissions.

12.7.1 Urban climate change mitigation plans and implementation

The growing motivation for city governments in climate change mitigation actions can be attributed to a variety of factors (Dhakal, 2010b). In some countries, sub-national municipalities are required by law to contribute to the national climate change policy. For example, in Japan, the Global Warming Law and the Kyoto Protocol Target Achievement Plan mandates that 1,800 municipal governments and 47 Prefectures prepare climate change mitigation action plans (Sugiyama and Takeuchi, 2008a). In other countries, the lack of federal government's leadership on climate change policy and local factors provide a political opportunity for city governments to take leadership and devise city climate action plans. For example, in the USA, cities and states have become leaders in developing climate change mitigation actions (Lutsey and Sperling, 2008). Between 2004 and 2007, 684 cities signed the US Mayors' Climate Protection Agreement, representing 26% of the US population and accounting for 23% of the country's GHG emissions (Lutsey and Sperling, 2008). Similarly, there are climate change efforts in many European cities despite a lack of national legislation for emissions targets (Bulkeley and Kern, 2006). Cities in emerging economies are also showing a willingness engage in and develop climate plans via non-obligatory commitments, including Beijing, Bangkok, Jakarta, Rio de Janeiro and Sao Paulo. These cities often are motivated because of the new funding and technology from international climate regimes, carbon markets, international bi-lateral and multilateral donors and other mechanisms. Some cities have developed strategies for low carbon economies such as solar energy in Baoding, China or environmental industries in Kitakyushu, Japan.

Given these diverse motivations, the courses of actions of cities for climate change mitigation are varied. Some cities have an overarching climate policy with targets and action plans. However, they vary in the level of specificity regarding the target: qualitative versus quantitative, short versus long term, baseline year and choice of indicator, feasibility of plans, rhetoric versus the ability to implement, and the sector under consideration (Bulkeley and Kern, 2006; Lutsey and Sperling, 2008; Wheeler, 2008; Sugiyama and Takeuchi, 2008b; Dhakal and Poruschi, 2010; Sippel, 2011). In addition, few selected cities such as Tokyo and Kyoto in Japan also play the role of a regulator (Sugiyama and Takeuchi, 2008b).

In recent years, increasing numbers of cities in developed countries have launched their climate change mitigation plans. Under the U.S. Mayor's Climate Protection Agreement, San Diego has an ambitious short-term target of 15% below 1990 by 2010, while longer-term goals have been set by Los Angeles (35% below 1990 levels by 2030), and Boston, Berkeley, and Santa Cruz (80% below 1990 levels by 2050) (Wheeler 2008). New York City's sustainability plan, PlaNYC 2030 aims to reduce greenhouse gas emissions by 30% from 2005 levels over the next 20 years (Rosenzweig et al., 2010). Assuming that all of the reduction targets are fully achieved by 684 cities in US Mayors' Climate Protection Agreement, a seven per cent reduction in overall US emissions would take place from the 2020 US baseline (Lutsey and Sperling, 2008). Likewise, the Berlin government adopted a Work Programme for Climate Protection (Action Plan) in July 2008. The reduction target was set to cut CO_2 emissions more than 40 % by 2020 compared to the level of 1990. In Copenhagen, the climate action plan "Carbon neutral by 2025: Copenhagen Climate Plan" was launched in 2009 with the goal to cut the city's CO_2 emissions by 20% between 2005 and 2015.

The key elements of city mitigation plans are quite diverse. For example, there are two types of base year for GHG mitigation. For the first type, the cities (e.g. London, Hamburg, Chicago) looked back to the year of 1990 according to Kyoto Protocol to set GHG reduction targets. The other type, some cities (e.g. Tokyo, Barcelona, Bangkok, etc.) set the base year of emission level as the years they launched their mitigation plans. As for the target years, 2050 is a common target year proposed for long-term efforts for GHG reduction. Other common target years for GHG mitigation include 2020 (e.g. Hamberg, Melbourne) and 2030 (e.g. New York, Bergen). The targets for GHG reduction are also very diverse for different cities, ranging from 10 percent (e.g. Sheffield) to 80 percent (e.g. Portland). As an example, Figure 12.7.1 shows the collective anticipated reduction potential of forty-two cities' mitigation plans with clear emission reduction targets and timelines. Most of these cases of city mitigation plans are from cities in developed countries, predominantly North American and European countries, with only fewer cases are from developing countries (e.g., Bangkok, Mexico City).These forty-two cities represent 159 million people from North America, Europe and Asia and emitted 503 $MtCO_2$ equivalent in 2005. Assuming all the reduction targets are achieved, they will collectively reduce GHG emission by more than 180 $MtCO_2$ -eq (equivalent to a 36% emission reduction of current figure) by 2050. Although the proposed reduction targets from cities are ambitious and, if realized, has potentials to contribute significantly to global climate change mitigation; however, the published literatures on the actual progress towards meeting these targets are limited.

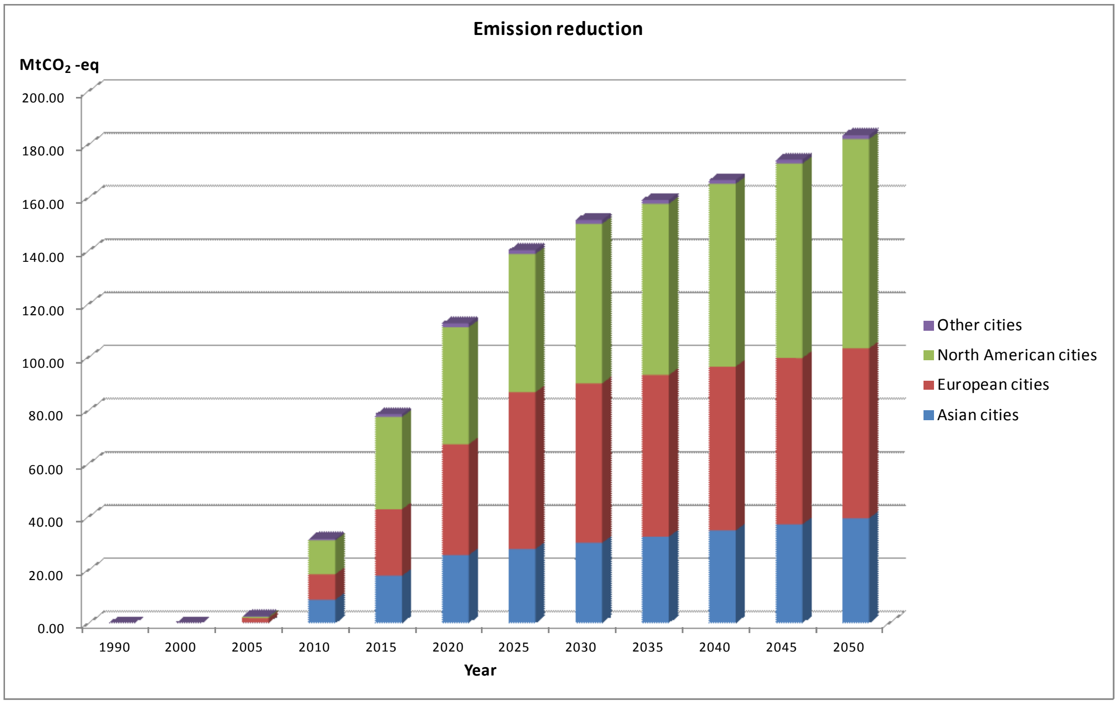


Figure 12.6 Mitigation potential of selected forty-two cities' based on their existing climate mitigation plans

Annotation:

1. Seventy city mitigation plans available from website were investigated, but only 42 cities have clear targets of GHG emission reduction and timeline.
2. Asian cities (12) : Kyoto, Tokyo, Yokohama, Kitakyushu, Sakai City, Iida City, Obihiro-shi, Toyama City, Toyoda City, Minamata City, Miyakojima, Bangkok; European cities (19): Stockholm, London, Paris, Aberdeen, Hannover, Hamburg, Sheffield, Barcelona, Hague, Hordaland, Stavanger, Copenhagen, Burgas, Bergen, Coventry, Exeter, Leicester, London, Coventry; North American cities (9) : New York, Portland, Houston, Vancouver, Chicago, Seattle, San Francisco, Philadelphia, Miami; Other cities (2): Melbourne, Kimberley.
3. Total population in all the case cities: 159 million

An example of climate change action plans for Tokyo is presented in Box 12.1. Tokyo presents a case of a serious climate action plan with clear targets- well ahead of the national policy, supplemented by mandatory local law, well-thought scientific accounting of GHG, actions and institutional capacity. At another end, Delhi's climate agenda is largely a preliminary attempt to develop climate actions while the city is confronting with the other basic priorities. Therefore, the climate action plans of cities may often look rosy but is not the case in many cities, especially in developing countries. For example, Delhi Climate Change Agenda only reports Delhi's CO_2 emissions from power, transport and domestic sectors as 22.49 $MtCO_2$ for 2007-8 (SOE Delhi, 2010) while the contribution of sectors such as commercial sectors and industries must be large for Delhi. Similarly, there are no clear overall GHG reduction targets to be achieved and how much carbon would be reduced by each of the stipulated actions of Delhi and how they will be achieved is not known. Similar is the case of City of Bangkok and Jakarta's climate mitigation plans (Dhakal and Poruschi, 2010). In many cities in the developing countries, a reliable city GHG inventory may not exist and the climate change actions could be largely symbolic and often cosmetic. However, these early city actions are yet positive for broader engagement of cities and they are prerequisite for building momentum for a bigger and collective action.

At the same time, despite having comprehensive plans and policies, the shortfall in progress and the uncertainty of achievements of targets confront cities in the developed countries. Often actions are highlighted but achievements are not evaluated. In Germany, many cities adopted ambitious targets in the past. Almost three out of four cities with a target have not adopted city wide targets based on local conditions but targets were externally influenced (based on international city networks and German national target) and they were not derived from analysis of mitigation options (Sippel, 2011). In Germany, cities' mitigation reduction performance is largely correlated to the national performance and the achievement of city targets are at a serious risk in all West German cities and also in all East German cities that depend on 'wall-fall' profits for target achievement (Sippel, 2011).

In other cities where clear targets and comprehensive climate plans have not been devised, climate actions are comprised largely of awareness building and individual project-based activities. This is especially the case for many cities in the developing world. In those cases, the impact of one or few individual project-based actions for GHG mitigation could be effective but small but they could be vulnerable to the rebound effect and leakage if they are not a part of the comprehensive mitigation plan.

Box 12.1 Climate change actions of Tokyo Metropolitan Government

Tokyo Metropolitan Government (Tokyo) aims to reduce GHG emissions from Tokyo by 25% below 2000 (or 19% below 1990) levels by 2020. Tokyo emits 59.6 $MtCO_2$ -eg annually for 2006 fiscal year or 4.8 tCO_2 -eq per person (TMG, 2010). Tokyo is world's first city to implement Cap-and-Trade Program for reducing CO_2 emissions. The Cap-and-Trade program started from April 2010 and it covers the CO_2 emissions from energy use in large scale businesses and buildings of commercial and industrial sectors. It includes factories, public buildings, commercial buildings and educational institutions. About 1,400 such facilities (about 1% to total in Tokyo) come under the cap that account for about 20% of total CO_2 emissions in Tokyo (or 13 $MtCO_2$). The allocation of emissions for facilities follows grandfathering method, where total emission allowance is the 94% of base year emissions (means 6% reductions) multiplied by the compliance period (5 years). The base year emission is an average emission of any three desired years within 2002-2007. There are separate provisions for new entrants. Facilities whose energy consumption falls below 1,500 KL threshold for 3 consecutive years are allowed to leave the scheme. A fixed emission factor is used in the scheme in order to avoid the complications such as the stoppage of nuclear power plants. Facilities are also required to verify emissions through licensed private audit firms. In the scheme, the first compliance period (FY 2010-2014) aims to reduce 6% from base-year emissions amongst the capped sectors finally reaching to 17% by the end of second compliance period (FY2015-2020). Facilities are allowed to "bank" the surplus within given compliance period but are not allowed to "borrow", in current compliance period, from the following compliance period. In case of non-compliance, a fine of JPY 500,000 coupled with additional reduction obligation beyond the shortfall is imposed and facilities are publicly disclosed (TMG, 2010; World Bank, 2010). The scheme aims to trade within Tokyo but also offers three type of flexibility. First, the facilities are allowed to buy credits from small/medium facilities inside Tokyo which are not part of the cap but are carrying out voluntary emission reduction (to be verified by the third party). Second, the provisions for applying credits from large facilities outside Tokyo are being developed with some purchase restriction. Third, the use of Renewable Energy Certificates of Japan is allowed. The scheme also provides measures to protect against a surge in trading price through Renewable Energy Certificates and other measures (TMG, 2010).

For low carbon urban development, a range of policies are put into place in Tokyo. Tokyo Green Building Program requires new buildings with 10,000 floor area or larger to submit the environmental performance rating document. In addition, the building owners are required to pursue sustainable design according to the Tokyo guideline, and rated results go to public information disclosure system. About 1,500 buildings are under this program by early 2008 (TMG, 2008). Tokyo has made low carbon prerequisite for large urban development with standards on insulation and energy efficiency in building equipment. A separate Tokyo's Green Labelling Program for Condominiums requires the developers of large condominium to display environmental performance labelling (with three stars) for sale. A new District Energy Program for efficient use has recently been established in Tokyo. From 2009, Tokyo started a subsidy system for solar energy equipment. In 2009-2010 alone 40,000 households have installed solar energy facilities in Tokyo. The system provides subsidy of 300 thousand Yen for photovoltaic system (3kw), 200 thousand Yen for solar heat system ($6m^2$), and 30 thousand yen for solar hot water supplier (4 m^2). The distinctions of Tokyo's program, from the national subsidy scheme are the prolonged application period for Tokyo city subsidies and the larger amounts of funds availability. In order to reduce CO_2 emissions from transportation, TMG program includes the promotion of use of low fuel consumption vehicle, reduce fuel consumption through improving average travelling speed, promote eco-driving, and vehicular traffic management. Source: (Dhakal and Poruschi, 2010)

The climate change mitigation plans do not work in isolation with other city plans. Climate change mitigation plans are often part of larger sustainability plans, mixed with urban development projects, or embedded in the spatial plans (Table 12.7.1). The extent to which climate mitigation plans are integrated varies extensively across cities. In U.S., most communities with climate change plans have included these policies in more comprehensive sustainability plans and often with a loss of focus on climate change (Wheeler, 2008). Some of the leader cities in US in this respect are Chicago, Seattle, Portland, and New York City. In New York, the climate action plan is actively pursued and is a part of a bigger sustainability plan. In Manchester and Madrid their plans are also part of wider sustainability strategies (Carter, 2011). There are also examples of city strategies focusing exclusively in mitigation, pursed with more importance than other city plans. The Mayor's Climate Change Action Plan of London, Tokyo Metropolitan Government's Carbon Minus Tokyo, New Amsterdam Climate of the Municipality of Amsterdam, Work Programme for Climate Protection (Action Plan) of City of Berlin set out an aggressive climate change mitigation agenda for their cities (GLA, 2007; ACO, 2008; TMG, 2010).

Mitigation actions have been also widely discussed and applied in the context of infrastructure investments and planning strategies for housing, improving energy efficiency, renewable energy, pollution control, urban transport, and economic re-structuring as evident from climate change plans and actions of cities. Energy efficiency and renewable energy are a favorite entry points in addressing climate change mitigation in many cities. In few cities, such as in Denver, New York, and Los Angeles, they also have initiated urban forestry expansion programs with the goals of adding one million trees in their climate change mitigation plans (Wheeler, 2008). There are also various examples of successful individual projects and schemes at the local level for helping to mitigating climate change. These include, for example, the city of Curitiba in Brazil which has been able to integrate transportation and land use through transit-oriented development (UN Habitat, 2011). This has led to emission reductions although the plan was not originally for GHG mitigation. In many countries spatial planning is also included in climate protection concerns. For example, the urban planning and design of Australian cities has, in the past, been regarded as a state, territory and local government responsibility; however, the Australian Government re-engaged directly with national urban and cities policy recently, due to significant decisions made by the Council of Australian Governments (COAG), including (1) establishing a set of national criteria for future strategic planning of capital cities, and (2) a related statement on national disaster resilience (DCCEE, 2010). In another example, in the city of Dhaka, strategic planning involves planning for sustainable urbanization. The potential to minimize climate change threats has been combined with a model of sustainable urbanization in the Dhaka Metropolitan Development Planning Support System (DMDPSS) (Roy, 2009a). Moreover, Germany (Wende et al., 2010) and the United Kingdom (Crawford and French, 2008b) have also applied the concept of integrating spatial planning and climate protection.

Table 12.3 Examples of different types of urban responses to mitigate climate change

Type of Plans	Examples
Integrated climate change or sustainability plans	· Tokyo Climate Change Strategy: A Basic Policy for the 10-Year Project for a Carbon-Minus Tokyo (TMG, 2008) · PLANYC (City of New York, 2007) · Chicago Climate Action Plan: Our City, Our Future (CCAO, 2008) · Climate Action Plan (Seattle, a Climate of Change: Meeting the

	Kyoto Challenge) (City of Seattle, 2006) · City of Madrid Plan for Efficient Use of Energy and Climate Change Prevention (Madrid City Council, 2008) · Manchester's Energy Strategy for 2005-2010 (City of Manchester, 2005) · Mexico City Climate Action Program 2008-2012 (De Buen Rodríguez, 2008)
Stand-alone mitigation plans	· Stockholm - a City for Climate Protection : Action Programme against Greenhouse Gas Emissions (City of Stockholm, 2008) · Kyoto Climate Change Policy (CCPOKC, 2003) · Action Today to Protect Tomorrow: The Mayor's Climate Change Action Plan (GLA, 2007) · Climate Action Plan: Local Action to Reduce Greenhouse Emission (*Climate Action Plan For San Francisco*, 2004) · New Amsterdam Climate (ACO, 2008) · Carbon neutral by 2025: Climate Plan Copenhagen (TEAC, 2009) · Climate Change Mitigation: a Strategic Approach for Cities (City of Toronto, 2010) · Action Plan on Global Warming Mitigation 2007 – 2012 (BMA, 2007)
Urban development projects (relevant plans)	· A master plan for low carbon and resilient housing: The 35 ha area in Hashtgerd New Town, Iran (Seelig, 2011) · Urban forestry expansion programs in US cities (Wheeler, 2008) · Planning for sustainable urbanization in fast growing cities: Mitigation and adaptation issues addressed in Dhaka (Roy, 2009a)
Mitigation programs embedded in urban spatial plans	· Seoul: A Clean and Attractive Global City- Four-year Plan (2006-2010) (City of Seoul, 2006) · A low carbon and resilient urban future: An integrated approach to planning for climate change (DCCEE, 2010)

12.7.2 Mitigation strategies of urban climate change plans

There is a broad range of strategies and activities envisioned in urban climate action mitigation plans. Key distinctions in those strategies include: comprehensiveness of strategies covering multiple sectors, single sector focus, choice of policy instruments, and early entry points and availability of larger co-benefits. In some cases, the governments make comprehensive plans to promote reduction of CO_2 to decrease the negative impacts of greenhouse gas emission. For example, in Mexico, the overall goal of the Mexico City Climate Action Program (Gobierno Del Distrito Federal, 2008) is to “Integrate, coordinate, and encourage public actions in the capital city to diminish environmental, social, and economic risks stemming from climate change and to promote the welfare of the population through the reduction and capture of greenhouse gas emissions.” The Mexico City Climate Action Program contemplates actions in five key areas: energy, transportation, water, waste, and adaptation. A total of 26 greenhouse gas mitigation actions have been proposed in the Mexico City Climate Action Program. If they are all implemented, they will reduce the CO_2 equivalent emissions by 4.4 million tons a year, which represents 12% of the annual GHG emissions in Mexico City. However, these actions have not been fully implemented and the government aims to provide $56,152 million pesos for the implementation in the next five years.

In the case of London, London Climate Change Policy (Schroeder and Bulkeley, 2008a), a number of policies and measures have been put into place to reduce emissions of greenhouse gases – the most prominent of these, and the challenges they have encountered. These initiatives can be grouped in three broad terms: leadership; infrastructural change; and changing practice. In terms of leadership the engagement of the most senior politicians and civil servants in London with this issue, and key parts of the business community, has been critical. The government has prioritized the decentralization of energy generation, with an ambitious target of 25% of energy supply to be provided in this manner by 2025. In terms of changing practice, the twin focus has been on individual householders and companies.

Table 12.4 London’s Climate Change Policy Key Initiatives

Policy initiatives	Aims	Challenges
Planning – 20% reduction in CO_2 emissions through on site renewable	To reduce contribution of new development to climate change	Business opposition on basis of technical and financial feasibility; has led to biomass based energy supply and questions over its sustainability
Planning – energy hierarchy	To encourage development of CCHP to reduce the carbon intensity of energy supply in London	Business opposition to small scale generation; large scale generation needed to be economically efficient
Energy – 25% decentralized energy by 2025	To reduce to reduce the carbon intensity of energy supply in London and enhance energy security	National regulatory barriers; available technologies; public opinion
Energy – London ESCO (Energy Service Company)	To provide a means through which to deliver decentralized energy projects and establish markets	Some reticence amongst business community concerning the business model and track records of ESCOs
Domestic – DIY Planet Repairs	To provide information to educate the public about possible actions	Long history of such campaigns failing to make an impact
Domestic – Green Housing Program	To provide a single point of delivery for advice and	Financial security of the program; skills gap in the supply chain

	financial assistance for energy efficiency; to target particular groups to take action	
Domestic – Green Concierge Service	To provide a service for those able to pay for energy efficiency improvements to their homes	Financial security of the program; skills gap in the supply chain
Commercial – Better Buildings Partnership	To improve energy efficiency of commercial buildings	Seeking to address landlord/tenant issues; reflecting improvements made in property values
Commercial – Green 500	To provide a recognition package for large public and commercial organizations saving energy	Relevance and uptake; financial security
Commercial and Public Sector – Building Retrofit Program	To improve energy efficiency in public sector and commercial buildings through energy performance contracting	Roll out and financing beyond pilot buildings; engagement of commercial sector

In Los Angeles, the plan of "Green LA: An Action Plan to Lead the Nation In Fighting Global Warming" (Schroeder and Bulkeley, 2008b). The plan incorporated several already established measures targeting air pollution, water conservation and energy decentralization, as they are also reducing GHG emissions. It was put together with the help of the coalition Green LA (not to be confused with the city's action plan, also called Green LA), consisting of over 60 environmental and community-based organizations focusing largely on climate change. Green LA was formed in 2006 in response to the then new mayor's commitment to addressing environmental issues in the city, expressed in several speeches over the course of his first year in office. Under the policy framework discussed above, a number of policies and measures have been put into place to reduce emissions of greenhouse gases – the most prominent of these, and the challenges they have encountered.

Table 12.5 Los Angeles's climate change policy initiatives and challenges

Focus area	**Goals and opportunities**	**Challenges**
Energy-Renewable Energy Goal (20% ren. By 2010 and 35% by 2030)	Phase out contracts with out-of-state coal-fired power plants Expand solar, wind, biomass and geothermal sources of energy to meet increasing energy demand and address possible future energy scarcity	Resistance to coal phase-out from LADWP labour unions Environmental conflict: renewables vs. building additional transmission lines (renewable sources cannot be built along existing transmission lines)

Energy - Green Building Ordinance	Promote green building practices in the private sector and reduce the city's carbon emissions by more than 80,000 tons by 2012	Higher initial building cost Continuing urban sprawl (inability to increase population density and walkability and reduce commuter time without better public transportation)
Water - Water and Wastewater Integrated Resources Plan	Improve water, wastewater and runoff management in the city	Previous water recycling project had failed in the 1990s due to political opposition and Some public uncertainty about tab water quality
Transportation - Reduce carbon intensity of transportation	Convert 85% of city fleet and 100% of city refuse collection trucks, street sweepers and buses of the MTA to alternative fuels Promote and expand transit	NIMBYism – Example: delays in expansion of rail lines because certain neighborhoods "don't like the idea of the rail and the noise in their community" (Interviewee, September 2007)
Land use - Build transit oriented developments	Create a more livable city	Culture – single family homes and several cars per family is still the aspired life-style of people in Los Angeles
Waste– Curbside recycling; RENEW LA PORT - San Pedro Bay Ports Clean Air Action Plan (CAAP) AIRPORT - Green the Airports	Recycle 70% of trash by 2015 Develop facilities that will convert refuse to energy without incineration Reduce air pollution from oceangoing, cargo-handling and heavy-duty vehicles through alternative marine power Meet green building specifications, improve recycling, use alternative fuel sources, use recycled water, etc. Purchase approx. 10% green power	Further improve information flows Ships need to be retrofitted Sea-borne emissions have to be regulated internationally Air-borne emissions have to be regulated internationally
Open space and greening - Increase green space Green Economy - Promote green econ. Sector	Create 35 new parks by 2010 Revitalize the LA River Plant 1 million trees - 1999-2010: 48,000 trees or 4,000 trees per year Manage the city as an ecosystem Collaborate with	The public needs to get involved more and become a partner in these endeavors (1 million trees cannot be planted by a single person alone) City agencies are not yet working together sufficiently Some industries are still undermining these efforts

	private sector to offer effective incentives for the growth of local green businesses Certify green businesses	
Adaptation/ climate proof LA	Improve capacity and develop comprehensive plans to prepare for climate change effects on the city	Not yet a higher priority

In Chicago, every Chicago resident and business has a role to play in implementing the Chicago Climate Action Plan (CCAO, 2008), which will not only ensure a more livable climate for the world, but also for the city. The economy and quality of life could improve. Jobs could be created. New technologies will emerge. In this plan, the reduction of carbon emission is elaborated as the following table.

Table 12.6 The Chicago Climate Action Plan Outline

Initiatives	Aims
Energy efficient buildings	Retrofit 50 percent of commercial and industrial building stock, resulting in a 30 percent energy reduction = 1.3 $MMTCO_2e$ reduction; Improve efficiency of 50 percent of residential buildings to achieve a 30 percent reduction in energy used = 1.44 $MMTCO_2e$ reduction; Expand appliance trade-in and lightbulb replacement programs = .28 $MMTCO_2e$ reduction Improve water use efficiency in buildings as part of retrofits = .04 $MMTCO_2e$ reduction; Align Chicago's Energy Conservation Code with the latest international standards = 1.13 $MMTCO_2e$ reduction; Require all building renovations to meet green standards = .31 $MMTCO_2e$ reduction; Increase rooftop gardens to a total of 6,000 buildings citywide and plant an estimated 1 million trees = .17 $MMTCO_2e$ reduction; Encourage all Chicagoans to take easy steps to reduce their emissions by one metric ton of CO_2e per person = .8 $MMTCO_2e$ reduction
Clean & Renewable Energy Sources	Upgrade or repower 21 Illinois power plants = 2.5 $MMTCO_2e$ reduction; Raise efficiency standards for new and existing power generators = 1.04 $MMTCO_2e$ reduction; Procure enough renewable energy generation for Chicagoans to reduce electricity emissions by 20 percent = 3.0 $MMTCO_2e$ reduction; Increase efficient power generated onsite using distributed generation and

	combined heat and power = 1.12 $MMTCO_2e$ reduction; Double current household-scale renewable electricity generation = .28 $MMTCO_2e$ reduction
Improved Transportation Options	Invest in transit improvements and boost Chicago's transit system ridership by 30 percent = .83 $MMTCO_2e$ reduction; Provide incentives for transit use, such as pre-tax transit passes = .03 $MMTCO_2e$ reduction; Encourage development focused on public transit, walking and bicycle use = .63 $MMTCO_2e$ reduction; Increase the number of walking and biking trips to one million a year = .01 $MMTCO_2e$ reduction; Boost car sharing, carpooling and vanpooling = .5 $MMTCO_2e$ reduction; Improve the energy efficiency of fleets in Chicago, including buses, taxis and delivery vehicles = .21 $MMTCO_2e$ reduction; Advocate for the implementation of higher federal fuel efficiency standards = .51 $MMTCO_2$ reduction; Increase the supply and use of sustainable alternative fuels to Chicago vehicles = .68 $MMTCO_2e$ reduction; Support intercity high-speed passenger rail plan; Faster, more efficient freight movement, including support for CREATE = 1.61 $MMTCO_2e$ reduction
Reduced Waste & Industrial Pollution	Reduce, reuse and recycle 90 percent of the city's waste by 2020 = .84 $MMTCO_2e$ reduction; Promote use of alternative refrigerants in air conditioners and appliances = 1.16 $MMTCO_2e$ reduction Manage stormwater with green infrastructure = .1 $MMTCO_2e$ reduction

In some cases, local governments attempt to use financing instruments to promote low carbon emission projects. Usually, through this approach, the mitigation target will not be proposed specifically, and the relevant institutions will provide for a fund to promote the mitigation action. For example, in Bangkok, Greenhouse Gas Emissions and the Clean Technology Fund (CTF) was established to contribute to the demonstration, deployment, and transfer of low carbon technologies with a significant potential for long-term greenhouse gas emissions savings (Clean Technology Fund, 2009). With the CTF, Bangkok was thus able to enhance its greenhouse gas mitigation program based on a credible and verifiable emissions baseline. The CTF is providing $70 million for urban transformation in Bangkok to cofinance the development of a bus rapid transit (BRT) system for the city. CTF support is also cofinancing investments in energy efficiency for BMA facilities and public spaces, focusing on electrical appliances and air-conditioning. These investments will create unique opportunities for replication. Toronto's Climate Change, Clean Air and Sustainable Energy Action Plan (TEEO, 2007) takes action to cut greenhouse gas emissions, clean the air and create a sustainable energy future. The City will create a of $42 million

Toronto Energy Conservation Fund, supporting energy conservation initiatives in City facilities along with buildings in the Municipal, Educational sectors, Hospitals and not-for-profit sectors. In addition, the creation of a $20 million Toronto Green Energy Fund will be set out in order to support renewable energy installations in Toronto along with others accounting for an expenditure of $22 will be plans for the continued implementation of Deep Lake Water Cooling and energy efficiency and sustainability upgrades. An additional $1 million Tree Planting and Green Roof Initiatives will be funded by the Water Stabilization Reserve.

In the case of Tokyo, the government built a city-level emissions trading system (ETS), which covers energy-relatedCO_2, involving around 1,340 large installations, including industrial factories, public facilities, and educational institutions, as well as commercial buildings. Mandatory reporting of emissions from at least the year 2002 provided a rich data source and solid baseline for designing the ETS and setting compliance targets. With this ETS, the Tokyo Metropolitan Government (TMG) aims to reduce CO_2 emissions by at least six percent during the first compliance period (2010-2014), with the ultimate goal of a 25 percent reduction below 2000 levels by 2020. A number of key enabling conditions in Tokyo were critical for the development and implementation of the city's ETS (PADECO, 2010).

In some countries and regions, local governments take action of reducing carbon emission directly from residential, commercial buildings and enhancing energy efficiency. For example, Hong Kong is working towards achieving a reduction in energy intensity of at least 25% by 2030. In Hong Kong, buildings therefore account for 89% of the electricity consumed. Establishing individual building emissions in order to take appropriate actions to reduce emissions is therefore of major importance in the drive for sustainability. Organizations are invited to join "Green Hong Kong Carbon Audit" by signing the "Carbon Reduction Charter" and undertaking to carry out activities in support of greenhouse gas emission reduction. A set of "Guidelines to Account for and report on Greenhouse Gas Emissions and Removals for buildings (Commercial, Residential or Institutional Purpose) in Hong Kong" has been drawn up by the Environmental Protection Department and the Electrical and Mechanical Services Department. The Guidelines are intended to report on emissions and removals from commercial, institutional and residential buildings.

In Birmingham, the Climate Change Action Plan (2010) guides the city in achieving sustainable objectives for the near future through outlining eco-friendly opportunities and solutions to all stakeholders in order to be able to secure access to finance for delivery of actions in prospect of a better future. Amongst the main targets Birmingham is set to become a "Low Carbon Transition" city which means that the city will aims to minimize, reduce, reuse, recycle all waste; promote local food; use low carbon energy sources; raise awareness of social and encourage environmental responsibility. The plan ensures that engagement is implemented with Birmingham's citizens and businesses, who play a vital part in improving the energy efficiency of the city buildings. Over the period to 2026 Birmingham City Council will undertake a sustained reduction in CO_2 emissions in order to meet the 60% reduction in CO_2 emissions from Birmingham homes by 2026 based on 1990 figures. As stated in the document, this is an ambitious commitment bearing in mind the current government requirements of 34% reduction by 2022 and 80% reduction by 2050. Under the Local Area Agreement actions will be monitored to be able to assess the progress undertaken.

In Melbourne, the vision for climate change adaptation within the City of Melbourne Climate Change Adaptation Strategy (2009) is to foster resilience in the city's forest and form a blueprint to inform the unfolding of our future environmental and socio-economic benefits. The city plans to increase the usage of innovatory tools in order to be more in-tact with nature and to be able to effectively forecast future changes. The tools include thermal imaging; increased number of weather stations measuring human thermal comfort, increased canopy cover, porous asphalt. One of the most important however is the giving rise to Water Sensitive Urban Design which will increase stormwater harvesting and improve water quality. On the topic of emissions, the "Zero Net Emissions by 2020 Strategy" focuses on achieving economic growth, environmental improvement and social cohesion by "shifting mainstream business investment in buildings, plants and power generation over the next two decades". This will be done by reducing energy use in buildings across Melbourne by 50% and increasing renewable energy supply in the city by 22% by 2020.

Besides decreasing the energy consumption from buildings, some cities attempts to decrease energy consumption from transportation. In Vitoria-Gasteiz, the government tries to decrease energy consumption by decreasing the motor vehicle usage and promoting public transport and non-motor activities. In 2006 the City Council approved the “Vitoria-Gasteiz Climate Change Prevention Strategy 2006-2012”. At that time In Vitoria-Gasteiz, over 65% of total municipal greenhouse gas emissions were associated with the industrial and transport sector. The primary action was therefore to combat such elevated emissions by these particular sectors. The targets of the 2010-2020 Plan against Climate Change aim to reduce 25% of the greenhouse gas emissions in the next 8 years. The body implementing mitigative policies is the "Sustainability Observatory of Vitoria-Gasteiz" which was created in 2005 in order to promote sustainable development at local level in a holistic way. Meanwhile, the city represents strong commitment towards environmentally-friendly mobility through ongoing investment in pedestrian areas and cycle lanes. The provision of sidewalks, boulevards and cycle zones is a strong focus this is due to the fact that over 80% of the city’s population is employed within the municipal boundaries and henceforth travel by foot gains great popularity. Since 2008 the use of public transport in Vitoria-Gasteiz has increased by 44%. The efforts to combat climate change in Victoria-Gasteiz, Spain have lead the city to achieve the title of European Green Capital 2012. Victoria-Gasteiz has been an ICLEI member since 2010 the city is also participating in CIVITAS Initiative (*ICLEI*, 2012, *European Green Capital Award*).

The Darfur Alternative Energy Project was implemented in order to promote alternative energy uses alongside the “Keep Juba Green" campaign, launched by UNEP in June 2010. “Keep Juba Green” is working to reverse deforestation and renew greenhouse gas sinks by working with local communities to plant one million trees over the next year. In its actions UNEP outlines the importance of well-managed fuel woodlots to prevent further depletion of forests in Sudan. Good management practices can sustain agriculture even in seemingly arid and hostile environments. Managing the environment to address climate change and human impact is critical to achieving lasting solutions for the Darfur region. The solution to this problem is to promote improved fuel efficiency and greater use of alternative energy. With support from the Governments of the UK, Italy and the US, UNEP helped the Sudanese Government to draft environmental policy and legislation that will enhance national monitoring programs (UNEP, 2012).

Aiming at decreasing carbon emission, these countries take different methods. In general, these policies attempt to decrease carbon emission directly from human activities through reducing energy usage and promoting funds for new technology development. Usually, comprehensive strategy includes several single sectoral strategy, which seems to have evident effects on mitigation. Provision of funds for new technology and project development seems to be able to reduce carbon emission in a long run. Utilizing financing instruments or emission trading system is likely to decrease the carbon emission in some city or country but may lead to large amount of carbon emission in some rich cities or countries.

Table 12.7 Approaches and strategies of urban climate change mitigation

Approaches	City	Policy	Action
Financing instruments	Bangkok	Greenhouse Gas Emissions and the Clean Technology Fund	enhance its greenhouse gas mitigation program based on a credible and verifiable emissions baseline
	Toronto	Toronto Energy Conservation Fund	a fund of $42 million to support energy conservation initiatives in City facilities
Emission trading system	Tokyo	a city-level emissions trading system (ETS) covering energy-related CO_2	involving around 1,340 large installations, aiming to reduce CO_2 emissions by at least 6 percent during 2010-2014, with the ultimate goal of a 25 percent reduction below 2000 levels by 2020
Reducing carbon emission directly from buildings and enhancing energy efficiency	Hong Kong	Carbon Reduction Charter	undertaking activities in support of greenhouse gas emission reduction of at least 25% by 2030
	Birmingham	Climate Change Action Plan	outlining eco-friendly opportunities and solutions to all stakeholders, meeting the 60% reduction in CO_2 emissions from Birmingham homes based on 1990 figures by 2026
	Melbourne	Climate Change Adaptation Strategy	increasing the usage of innovatory tools in order to be more in-tact with nature and to be able to effectively forecast future changes
Comprehensive plans for promoting CO_2 reduction	Mexico City	Mexico City Climate Action Program	contemplating actions in five key areas: energy, transportation, water, waste, and adaptation; reducing the CO_2 equivalent emissions by 4.4 million tons a year..
	London	London's Climate Policy	To reduce contribution of new development to climate change; and to reduce the carbon intensity of energy supply in London and enhance energy security and efficiency.
	Los Angles	Green LA: An Action Plan to Lead the Nation In Fighting Global Warming	Encouraging renewable energy and green buildings; improving water, wastewater and runoff management; reducing carbon intensity of transportation; building transit oriented developments; establishing

			waste recycling system; increasing green space and promoting green economy.
	Chicago	The Chicago Climate Action Plan	Encouraging energy efficient buildings, clean and renewable energy sources, improved transportation options, reduced waste and industrial pollution and adaptation
	Sino-Singaporean Tianjin Eco-city	Labeled by "ecology, energy efficiency, environment protection, nature, livability and harmony"	Implementing an energy-efficient architectural standard system; constructing an energy-efficient traffic network system; building an energy-efficient energy supply system; enhancing the efforts to ecological restoration and protection; striving to build a low-carbon industrial system; building brand-new harmonious and livable community; pragmatic and Efficient Sino-Singaporean Cooperation
Decreasing motor vehicle usage and promoting public transport and non-motor activities	Vitoria-Gasteiz	2010-2020 Plan against Climate Change	to reduce 25% of the greenhouse gas emissions in the next 8 years
Reversing deforestation and renewing greenhouse gas sinks	Sudan	Keep Juba Green	working with local communities to plant one million trees and preventing further depletion of forests in Sudan, and promoting improved fuel efficiency and greater use of alternative energy

12.7.3 Opportunities for urban mitigation plans

One of the key opportunities for urban mitigation is to develop policies for the whole urban system and not only the sub-components and sectors. One example is to increase the efficiency of material use. One billion metric tons of raw materials are extracted globally each year, and rising between 1900 and 2005 by a factor of 8, with the most significant growth coming from construction materials, ores/industrial minerals and biomass (Krausmann et al., 2009; Steinberg et al., 2010). Cities will continue to exert demand on the non-renewable resources especially in recently urbanizing regions (Pulselli et al., 2008; Calkins, 2009; Steinberg et al., 2010). However, opportunities exists with scalable solutions by utilizing the resource stock in developed regions' cities(Escobedo et al., 2006; Mazzanti and Zoboli, 2008; Güneralp and Seto, 2012a).

Various mitigation strategies in European countries and some Global South cities such as Cape Town and Durban have been implemented to link climate change and economic growth(Arando Usón et al. 2011; Polimeni et al. 2009; Holden & Norland 2005)(Roberts, 2008)(Liu and Deng, 2011). Decoupling of resource utilization and economic growth at multiple scales is underway in some US cities and developing regions like Chile (Kamal-Chaoui and Robert, 2009b; OECD, 2010; Suzuki et al., 2010). Resource decoupling involves less use of primary resources for the same economic output(Ress, 1992)(Fields, 2009). Impact decoupling on the other hand involves reducing relation between economic output and negative environmental impacts (Venkatesh & Brattebø n.d.; Hunt & Watkiss 2010; Bowman et al. 2000; Litman 20110825). Cities can play a significant role in resource decoupling and this will require innovative cities taking appropriate strategic approach to greatly enhance resource efficiency while simultaneously decreasing GHG emissions (Hodson and Marvin, 2009b; Fields, 2009; Antrobus, 2011).

Payment for ecosystem services as a supporting hand to sustainable urban development could be an opportunity well linked to climate change actions (Hodson and Marvin, 2009a; Suzuki et al., 2010). While the traditional focus of such endeavor lie with rural environments, carbon sequestration and storage programs could provide some opportunities in cities through programs for green rooftops, urban forestry, greening catchments and permaculture (Escobedo et al., 2006; Stoffberg et al., 2010; Davies et al., 2011). Evidence exists on green city carbon storage, carbon stocks in built materials of cities and potential along urban-rural gradients (Carter and Fowler, 2008; Fields, 2009). These programs and strategies have a clear link and relevance to urban areas but the extent and ability of which is less known. However, such approach would require investments in ecosystem services including urban forestry, catchment restoration, urban agriculture along the urban and peri-urban gradient across the city regions. Few cities such as London, Copenhagen, Kuala Lumpur have adapted the spatial development pattern of natural green patches interwoven with agricultural fields that provide ecosystem services of provisioning and regulation (Wilson, 2009). In these cities programs have been developed with local communities and are proving an effective strategy to mitigate climate change and a way to increase resilience.

Payment for ecosystem services has a potential for innovating around green jobs in cities that reduce negative environmental impacts. A strategy to green the economy involves environmental and social full-cost pricing of energy and materials inputs, in order to ameliorate unsustainable patterns of production and consumption(Hodson and Marvin, 2009b; Maller et al., 2011). Infrastructure in cities will be key to link climate change mitigation with economic growth. Green technologies, mass transit systems that utilize renewable energy have a potential for enabling synergies between mitigation and economic growth (World Bank, 2009).

12.8 Sustainable development, co-benefits, tradeoffs, and spillover effects

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

12.8.1 Sustainable development challenges at the urban scale

Historically, better health and living conditions in urban centres are associated with higher emissions and larger footprints. For low and middle-income nations, the challenge is how to ensure that urban centres can reduce poverty and become healthy, safe and desirable places to live and work while limiting the increase in their levels of emissions and footprint. For wealthy nations, the challenge is to retain or enhance their quality of life and economic base while radically reducing their emissions and footprint (Satterthwaite, 2007). There also are important differences within and between cities. Affluence and wealth have an important impact on the environmental quality of a city, and affect the nature of their environmental problems. In poor cities, environmental burdens tend to be localized – often at the neighbourhood level - immediate and health threatening and typically include lack or inadequate access to essential services such as water and sanitation and shelter. In middle-income cities, environmental problems are associated with increases in fossil fuel combustion for industrial activities and urban transport, and are no longer localized but affect the whole city as well as its surrounding region, for example through industrial pollution of surface and groundwater and the need to dispose of solid and hazardous wastes (Lee, 2006). In wealthy cities, environmental threats to the health of residents are largely solved but carbon emissions are the highest, often through consumption rather than production, with global rather than localized or regional impacts, and long-term, intergenerational implications (McGranahan et al, 2001).

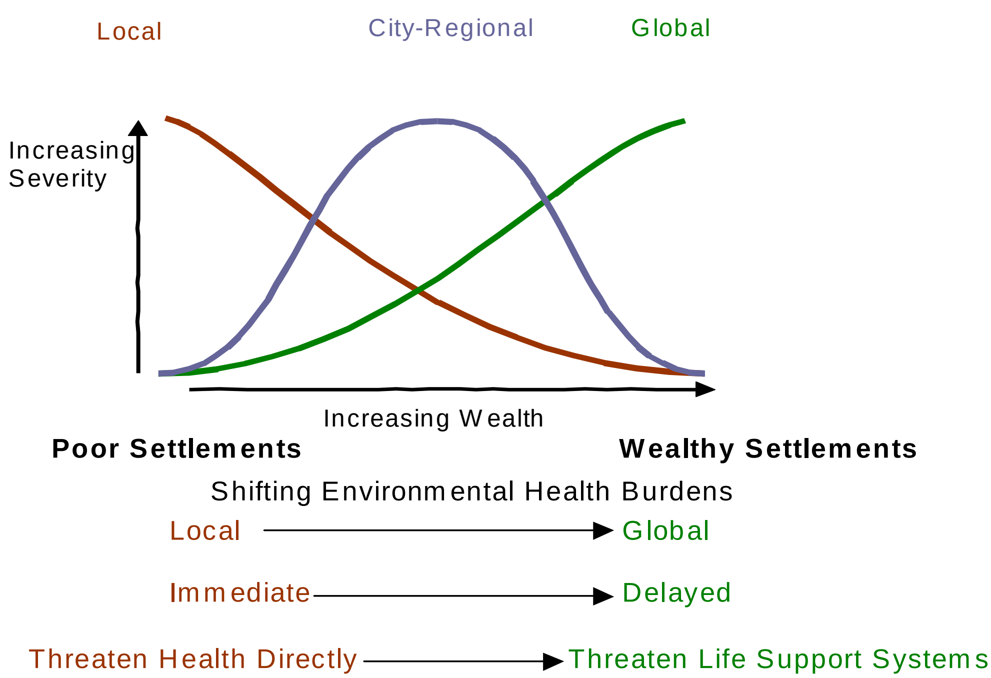


Figure 12.7 Shifting environmental burden and wealth. [Note from the TSU: Source: McGranahan et al, 2001... zotero reference missing]

12.8.2 Co-benefits and tradeoffs of sustainable development strategies

At times, adaptation and mitigation interventions to reduce climate change risks are constrained by developmental pressures (Mcevoy et al., 2006). For example, energy efficiency related mitigation measures are considered as the low hanging fruits of a city's responses to climate change (Dodman, 2009b). However, implementing these measures in existing infrastructure might generate waste in the form of previous functional devices becoming redundant. Another example of conflict is the 'density conundrum' for urban form and design. Mitigation calls for densification of urban environments to reduce carbon footprints while adaptation requires open urban spaces for storm water management, urban cooling and species migration (Kithiia, 2011). Climate change mitigation and adaptation measures are at times associated with conflicts and trade-offs of competing goals of sustainable development strategies and hence is a decisional challenge for planners and the city administration (Table 1). Further, mitigation strategies for cities may be limited if their emissions reduction targets are achieved by outsourcing emission-intensive industries.

Research has lagged behind in quantitative assessments of climate change impacts on cities, especially inland cities, and cost benefit assessment of climate change mitigation and adaptation measures over different time scales (Corfee-Morlot et al., 2010; Birkmann et al., 2010; Hunt and Watkiss, 2010b). The key issue underlying all these research gaps is the lack of robust and useful data to do various analysis, incongruence and weak coordination between government departments and various sectors implementing climate change and sustainable development strategies, and the lack of coherency in these measures (Hamin and Gurran, 2009; Birkmann et al., 2010).

Table 12.8 Key urban mitigation strategies and their linkage with adaptation, other sectoral benefits and trade-offs

Urban strategies	Climate change mitigation measures	Climate change adaptation measures	Examples of probable co-benefits	Examples of probable conflicts/trade-offs	Synergistic action and implications on sustainable development strategies
Land use plan and urban design	Urban land use planning with focus on creation of 'green' and 'blue' spaces; compact and multifunctional urban structures so as to reduce commuting distance; limiting urban sprawl; use of brownfield land;	Revision of urban land use plan with respect to projection scenarios of climate change and hence occurrence of extreme weather events, e.g., re-assess construction in low-lying coastal areas, protect wetlands, mangroves and other coastal eco-systems, building channels and lining riverbeds; construction of dykes, levees, groins, off-shore breakwaters, etc.; pervious surfaces; improved storm water drainage systems	Reduction in GHGs emission; reduction in urban heat island effect; promotion of tourism industry; maintenance of traditional livelihoods; biodiversity protection; improved ecosystem services; recharge of underground aquifers;	Might conflict with current livelihoods of the people and land tenure; might involve a trade off with water & energy consumption reduction goals due to maintenance of green belts; harm to infrastructure due to falling of trees during severe storms. May disproportionally affect residents of informal settlements and with no secure tenure rights	Adaptation and mitigation measures can be mainstreamed with land use and development plans. For example, it is important to integrate the analysis of built environment systems, energy, emissions, and materials in combined studies of the socio-economic metabolism.
	Prohibiting deforestation and promoting afforestation; xeriscaping in arid and semi- arid regions; creating urban wildscapes and greenscapes as carbon sinks	Urban agriculture, urban landscape rehabilitation	Increased opportunity for forest based recreation activities, enhancement in local economy and livelihood creation; reduced risk or extent of flooding and improved urban microclimate.	Conflict with urban density and compactness; might involve a trade-off with economic development priorities of the urban centres and water & energy savings goals due to maintenance of green belts, negative health outcomes and costs due to allergies (pollen)	Promotion of urban agriculture creates a win-win-win situation for mitigation, adaptation and sustainable development strategies, including enhanced resilience of ecosystems.
		Investment in weather forecasting systems; warning systems	Reduced morbidity and mortality due to heat and cold waves,	Might conflict with economic and other developmental priorities of the urban	Such adaptation measures and local sustainable development strategies

		(temperature extremes, air quality, storms, precipitation, forest fires); capacity building of local governments, disaster management and response teams and communities	air pollution and weather related disasters and catastrophes	centres, e.g. provision of basic services to the population	interact synergistically
		Promoting livelihood diversity; improved access to credit and insurance and healthcare establishments; bridging the 'digital' divide by providing access to improved ICT systems in municipal or community offices	Reduction in vulnerability of the population and improved well being	Conflict with market based economic systems	Such adaptation measures and local sustainable development strategies interact synergistically
Building Materials and Design	Use of recycled materials and energy and water efficient fittings in the construction of new infrastructure; increasing albedo	Zoning regulations and building code formulations or re-visit based on future climate change scenarios	Mineral resource conservation, recycling materials (waste to wealth) industry and generation of new economic opportunities; reduction in expenditures in procurement of energy; reduced GHG emissions; water resource sustainability; reduction in urban heat island effect	Possibility of conflicts with land tenure, availability of areas for new development; high costs	*Win-win* situation for climate change mitigation and LSD objectives
	Use of renewable energy or low-carbon energy sources	Installation of air-conditioners; passive cooling design, e.g., shading; insulators and	Protection of the vulnerable population prone to temperature extremes,	Increase in GHG emissions in the absence of low-carbon or renewable energy source	

		heating systems			
	Retrofitting with energy and water efficient devices	Awareness creation/raising programs on efficient energy use and water conservation for residential communities and commercial buildings	Reduction in expenditures on purchased energy	Retrofitting the existing infrastructure might be capital intensive; might require a trade-off with the aesthetic value of heritage buildings and cities	Win-win-win situation for climate change mitigation, adaptation and local sustainable development (LSD) strategies
Infrastructure related to provision of clean water services	Using energy efficient water treatment and pumping systems and devices; improved design to reduce water loss during transit	Promotion of water conservation measures and demand management; watershed management; desalination plants	Sustainability of fresh water resources	Setting up of desalination plants might have a trade-off with GHGs emission reduction goals	Use of energy efficient systems and promotion of water conservation measures and demand management creates a *win-win-win* situation with regard to climate change mitigation, adaptation and local sustainable development strategies
Infrastructure related to waste and wastewater management	Installation of energy efficient maintenance fixtures and devices; policies for extraction and use of landfill gas; avoidance of residual landfill gas through in-situ aeration; behavioural changes for environmentally friendly consumption	Encouraging optimal design (centralised or decentralised) of waste and wastewater collection and treatment systems; capacity building of population regarding need for segregation and disposal of wastes; waste recycling; water recycling	Carbon financing under CDM; reduced GHGs emissions; reduced risk of vector borne diseases and negative health outcomes; mineral and natural resource conservation	Might conflict with existing infrastructure and availability of additional land area; might involve a trade off with goals of indigenous service procurement since planning, designing and maintenance might get 'outsourced' Informal settlements may be left out of plans although they often the most at risk	*Win-win-win* situation with regard to climate change mitigation, adaptation and local sustainable development strategies
Transportation	Deployment of fuel efficient carriers; policies and infrastructure regarding switch to alternative fuels; use of lighter materials as structural and energy storage parts	Improvement in transportation planning and infrastructure which provides people with access to multimodal public transportation options; pedestrian and bicycle friendly transits	Reduced air pollution; improved health outcomes; reduction in commuting time due to less congestion	Might conflict with current transportation systems and refuelling infrastructure which are cheaper and reliable; might involve a trade off with passenger safety and GHGs emission reduction goals due to increased usage of fuel	Provision of multimodal transportation infrastructure and deployment of fuel efficient carriers creates a win-win-win scenario for implementation of mitigation, adaptation and local sustainable development measures

				efficient vehicle	

Sources: (Anon, 2007; Roy, 2009b; Hunt and Watkiss, 2010a; Ritzkowski and Stegmann, 2010; Birkmann et al., 2010; United Nations Human Settlements Programme., 2011).

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

The urban heat island effect illustrates the co-benefits and trade-offs among sustainable development, climate change mitigation and adaptation strategies in settlements. The urban heat island (UHI) effect, in which urban areas are warmer than surrounding areas has been observed since at least 1833 (Myrup, 1969), in part due to absorption of solar radiation by dark surfaces, such as roofs and pavement, and re-radiation from urban structures (RIZWAN et al., 2008). In dense cities such as Tokyo, the density of heat discharge in city by buildings due to air conditioners is high and energy can contribute to 3-4 ^{o}C in heat island (Dhakal and Hanaki, 2002). Various approaches have been used to simulate UHI mitigation, and important parameters include latent, sensible, storage and anthropogenic heat (such as from air conditioners and internal combustion engines), as well as how radiation, effects of trees and ponds, and boundary conditions are treated (Mirzaei and Haghighat, 2010). The UHI effect varies by time of day and season, and spatially, and is typically stronger at night than during the day; UHI increases with increased population, increased income and energy consumption, and conversion of land from agricultural uses to paved surfaces (Zhang et al., 2009). The UHI presents a major challenge to urban sustainability, not only does UHI increase the use of energy for cooling buildings and thermal discomfort in urban areas, but UHI increases smoggy days in urban areas, and smog has health effects above 32 degrees C (Akbari et al., 2001).

The UHI effect can be mitigated by using shade trees and “cool” materials that are more reflective (absorb less solar radiation), i.e., increasing the albedo of the surfaces (Akbari et al., 2008; Akbari, 2010). Calculations based upon physical principles indicate that the effect of substituting cool materials is significant, resulting in cooler temperatures. In addition to white roofs or pavements, a range of cool materials in a variety of colours have been developed which reduce absorption of solar radiation. On a global scale, increasing albedos of urban roofs and paved surfaces is estimated to induce a negative radiative forcing equivalent to offsetting about 44 Gt of CO2 emissions (Akbari et al., 2008).

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

As temperatures rise due to climate change, mitigation of the urban heat island is synergistic with adaptation to climate change. Model results for large-scale deployment of cool roofs and photovoltaic arrays indicate reduced afternoon summertime temperature in urban locations of -0.11-0.53 degrees C, with some urban areas showing no statistical change (Millstein and Menon, 2011).

Proven methods for cooling the urban environment include urban greening, using high-reflectivity materials, and increasing openness to allow cooling winds (Smith and Levermore, 2008). Reducing UHI will need to be considered in conjunction with other environmental aspects of urban design, including solar/daylight control, ventilation and indoor environment, and streetscape (Yang et al., 2010). Some researchers suggest that heat island mitigation be based on human comfort rather than only controlling air temperature (Emmanuel and Fernando, 2007). Simulation of heat mitigation strategies in New York City found that increasing the albedo of surfaces was most effective at reducing air temperatures, but caused increased thermal stress for people at street level; analysis indicated that planting trees at street level and increasing the reflectivity of roofs provided a better integrated solution (Lynn et al., 2009). Simulation of four UHI mitigation strategies in combination shows potential for 48% reduction in annual heat-related emergency service calls in Phoenix, Arizona (Silva et al., 2009). In Tokyo, among nine scenarios comprising of location and type of air conditioning system, urban greening and albedo improvement, the maximum improvement in average temperature for daytime was found to be 0.47°C (at noon) as a result of greening the areas around the buildings of Tokyo. Similarly, the maximum improvement in average temperature for the evening was found to be 0.11°C by discharging all heat to the ground (Dhakal and Hanaki, 2002).

Field studies demonstrate effects of mitigation with green spaces including: i) decreasing temperatures in Athens (up to 2 degrees C, (Gaitani et al., 2011)); Lisbon (Oliveira et al., 2011); New York City (Susca et al., 2011); ii) trees and grass in reducing human thermal stress (Shashua-Bar et al., 2011). In Japan, sprinkling pavement with reclaimed wastewater reduced road surface temperatures by 8 degrees at night and 3 degrees during the day (Yamagata et al., 2008).

The projected temperature increases under climate change will disproportionally impact cities already affected by UHI, thereby increasing the energy requirements for cooling buildings and increasing urban carbon emissions, as well as air pollution. In addition, there is likely to be an increase in cities experiencing UHI as a result of projected increases in temperature under climate change, which will result in additional global urban energy use, GHG emissions, and local air pollution. As reviewed here, studies indicate that several strategies are effective in decreasing the UHI. An effective strategy to mitigate UHI through increasing green spaces, however, can potentially conflict with a major urban climate change mitigation strategy, increasing densities to create more compact cities, the density conundrum discussed in section 12.5. This illustrates the complexity of developing integrated and effective climate change policies for urban areas.

12.8.4 Urban carbon sinks

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

Most studies that assess the extent of carbon sequestration in cities have been conducted in western countries, and limited information is available for cities outside Europe and the USA. In the USA, urban forests are estimated to sequester an average of 25.1 t C ha^{-1} above ground, less than half of that for forest stands (David J. Nowak and Crane 2002). The total organic carbon sequestered in urban vegetation and soils can be as high as 115.6 t ha^{-1} in the USA, much greater than those of rural forest soils (Pouyat et al., 2008; Churkina et al., 2010). In European cities, above ground C sequestration is estimated to be an average of 31.6 t ha^{-1} in Leicester, UK (Davies et al., 2011), 11.8 t ha^{-1} in Leipzig, Germany (Strohbach and Haase 2012), and 11.2 t ha^{-1} in Barcelona, Spain (Chaparro and Tarradas 2009). In the South Korean cities of Chuncheon, Kangleung and Seoul, mean above and belowground carbon storage is estimated to be much lower, ranging from 4.7 to 7.2 t ha^{-1} (Hyun-kil, 2002), while in Hangzhou, China, above ground carbon sequestration is estimated to be much higher, 30.3 t ha^{-1} (Zhao et al.2010). Thus there are considerable differences between reported values from different cities. It is difficult to establish comparisons, in part due to the differences in methodologies of estimation, but mainly due to critical differences in the definition of urban areas, with some city studies including natural forests, parks and built areas within urban boundaries, while others focus mainly on urban forests.

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

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

Lawns and turfgrass constitute common urban features, and provide some, albeit limited opportunities for C sequestration. Golf courses in the US have average annual rates of sequestration of 0.9-1 t C ha^{-1} during the first 25-30 years after establishment (Qian, Yaling and Follet, Ronald F., 2002). Carbon sequestration in urban lawns and turfgrass soils can substantially surpass initial levels in less than two decades and exceed those of production agriculture and tallgrass prairie, due to intensive management, irrigation and fertilization (Qian, Yaling and Follet, Ronald F., 2002; Pataki et al., 2006; Golubiewski, 2006; Pouyat et al., 2008). Green roofs and green walls provide another, currently limited but fast growing category of urban green space with potential for large scale modification through planting (Yang et al., 2008; Getter et al., 2009).

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

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

12.9 Gaps in knowledge

City governments and civil society are taking leadership to reduce carbon emissions, but there are few evaluations of these local climate action plans and their effectiveness. There is a need for standardized methodologies for city-level carbon accounting.

12.10 Frequently Asked Questions

FAQ 12.1 How much do urban areas contribute to climate emissions?

The contributions of urban areas to total global CO2 emissions from energy use range from 60-70%. This is based on production side accounting of CO2 including electricity. However, based on multiple definitions of urban areas the figures could be different. If CO2 emissions are allocated to consumption, the figures would be different.

FAQ 12.2 What are the potential of cities to mitigate climate change (given their relatively small percent of the global land area)?

The spatial organization of human settlements is one of the major factors that determine energy use and emissions through the layout of streets and buildings, accessibility to jobs and markets, infrastructure investments, and transportation corridors. Once in place, the basic spatial structures of human settlements are difficult to change. In turn, the spatiality of settlements, especially cities, shapes transport choices, housing options, building types, and ultimately lifestyles. As a system, human settlements can increase the efficiency of infrastructure and energy use beyond what is possible with individual sectoral components.

FAQ 12.3 Why is the IPCC including a new chapter on spatial planning and human settlements? Isn't this covered in the individual sectoral chapters?

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

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