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

12.3.1.2 Interdependence between drivers

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

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

12.3.1.3 Human settlements, linkages to sectors, and policies

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

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

12.3.2 Weighing of drivers

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

12.3.2.1 Qualitative weighting

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

Importance of size and scaling

Given the significance of human settlements for global resource use, an improved understanding of their size distribution and likely growth dynamics is crucial. For many physical, biological, social, and technological systems, robust quantitative regularities like stable patterns of rank distributions have been observed. Examples of such power law-scaling patterns include phenomena like the frequency of vocabulary in languages, the hierarchy of urban population sizes across the world (Zipf, 1949; Berry and Garrison, 1958; Krugman, 1996) or the allometric scaling patterns in biology, such as Kleiber's Law, which observes the astonishing constancy in the relation between body mass and metabolic rates: for living organisms across many orders of magnitude in size that metabolic rate scales to the ¾ power of the body mass (Kleiber, 1961). There is a vigorous debate in many fields, including

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

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

Geography (Batty, 2007, 2008), Ecology (Levin, 1992; West et al., 1999; Brown et al., 2004), Architecture (Weinstock, 2011), and Physics (Carvalho and Penn, 2004) about the extent to which underlying hierarchical networks of metabolic systems or transportation networks are the ultimate causes of the size, shape and rank-distribution of entities, be they organisms or urban systems (Decker et al., 2000, 2007).

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

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

Mature versus growing cities

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

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

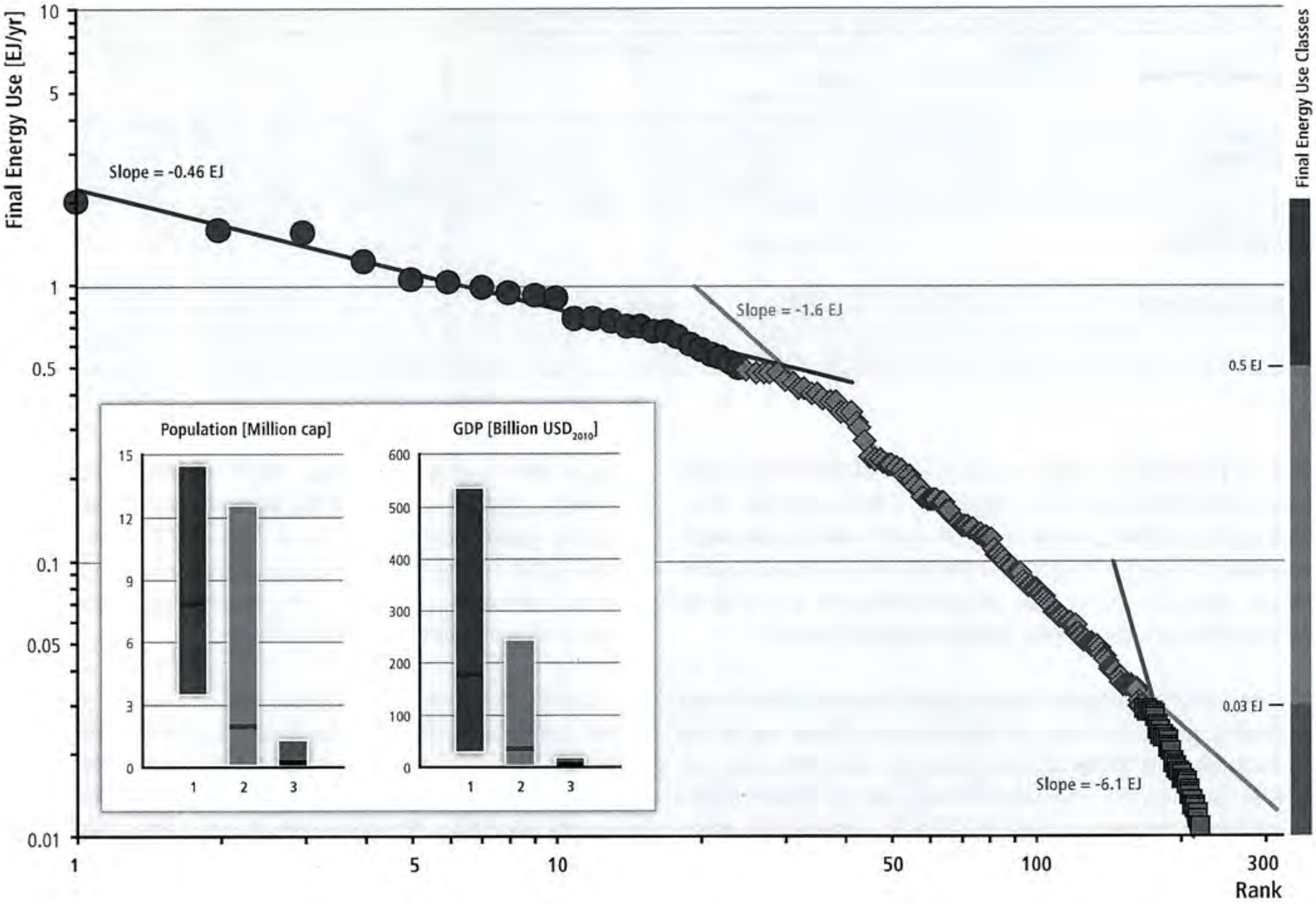


Figure 12.10 | Rank size distribution of 225 cities in terms of their final energy use (in EJ) regrouped into 3 subsamples (> 0.5EJ, 0.03–0.5EJ, < 0.03EJ) and corresponding sample statistics. The rank of a city is its position in the list of all cities sorted by size, measured in terms of final energy use. Note the different elasticities of energy use with respect to changes in urban size rank. The factors (slopes) shown in the figure detail the increase of energy use when doubling the rank for the respective groups. Source: Grubler et al. (2012) based on Grubler and Schulz (2013).

Specialization in energy-intensive sectors creates a strong correlation between economic growth and GHG emissions growth. This relationship is further strengthened if the energy supply mix is carbon intensive (Parikh and Shukla, 1995; Sugar et al., 2012).

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

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

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

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

12.3.2.2 Relative weighting of drivers for sectoral mitigation options

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

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

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

12.3.2.3 Quantitative modelling to determine driver weights

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

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

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

12.3.2.4 Conclusions on drivers of GHG emissions at the urban scale

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

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

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

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

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

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

12.4 Urban form and infrastructure

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

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

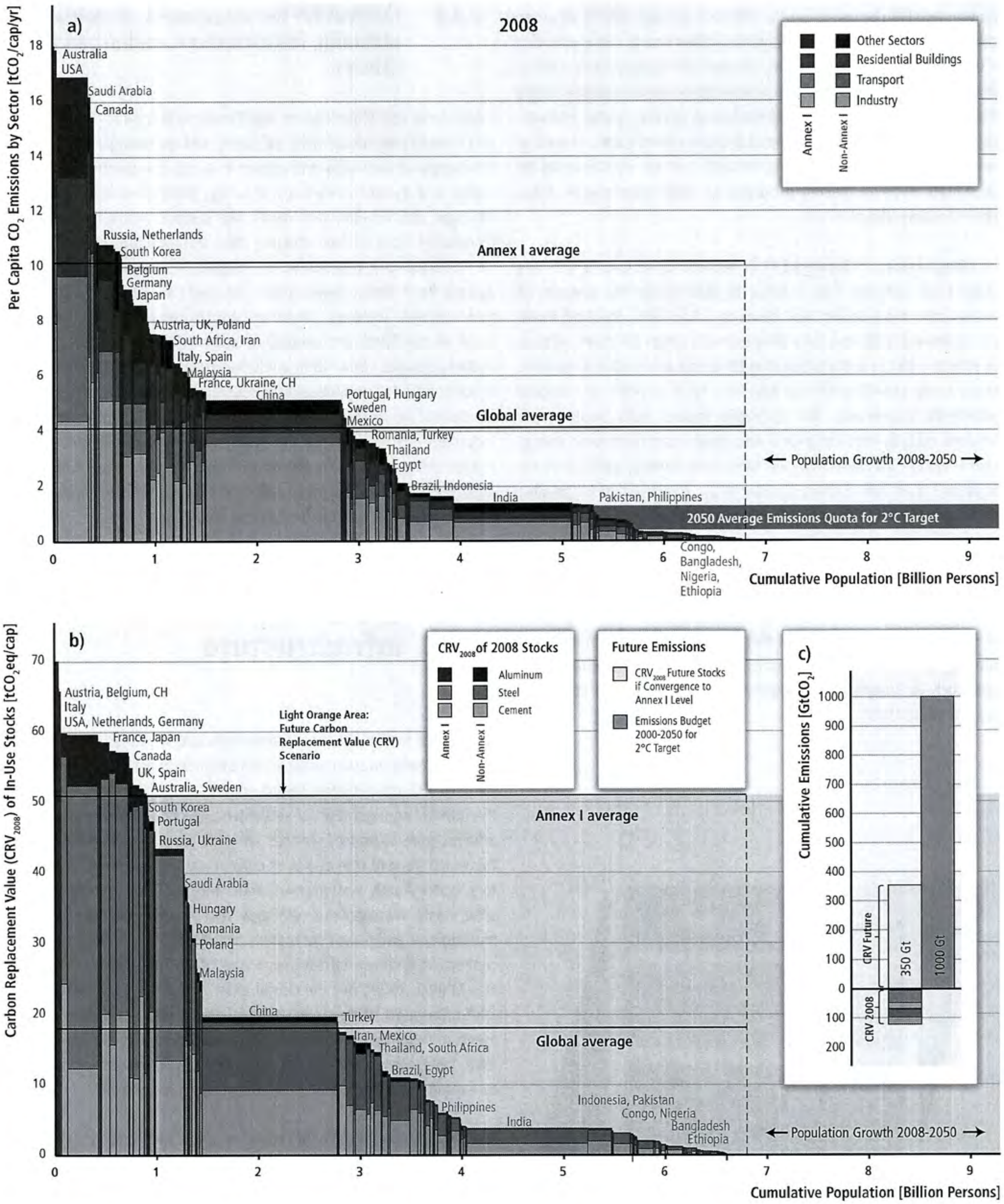


Figure 12.12 | (a) Total fuel-related per-capita CO_2 emissions in 2008 by country (red/orange/yellow and blue bars) compared to the global per-capita emission level in 2050 to reach the 2 °C target with a 50–75 % probability; (b) Carbon Replacement Value (CRV_{2008}) per capita of existing stocks by country (red/orange and blue) and as yet unbuilt stocks if developing countries converge on the current average Annex I level (light yellow background area); (c) comparison with emission budget for the period 2000–2050 to reach the 2 °C target with a 75 % probability. Of this emission budget (1000 Gt CO_2), approximately 420 GtCO2 was already emitted during the period from 2000 to 2011.Source: Müller et al. (2013).

particularly limited. This assessment reflects this limitation in the literature.

12.4.1 Infrastructure

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

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

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

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

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

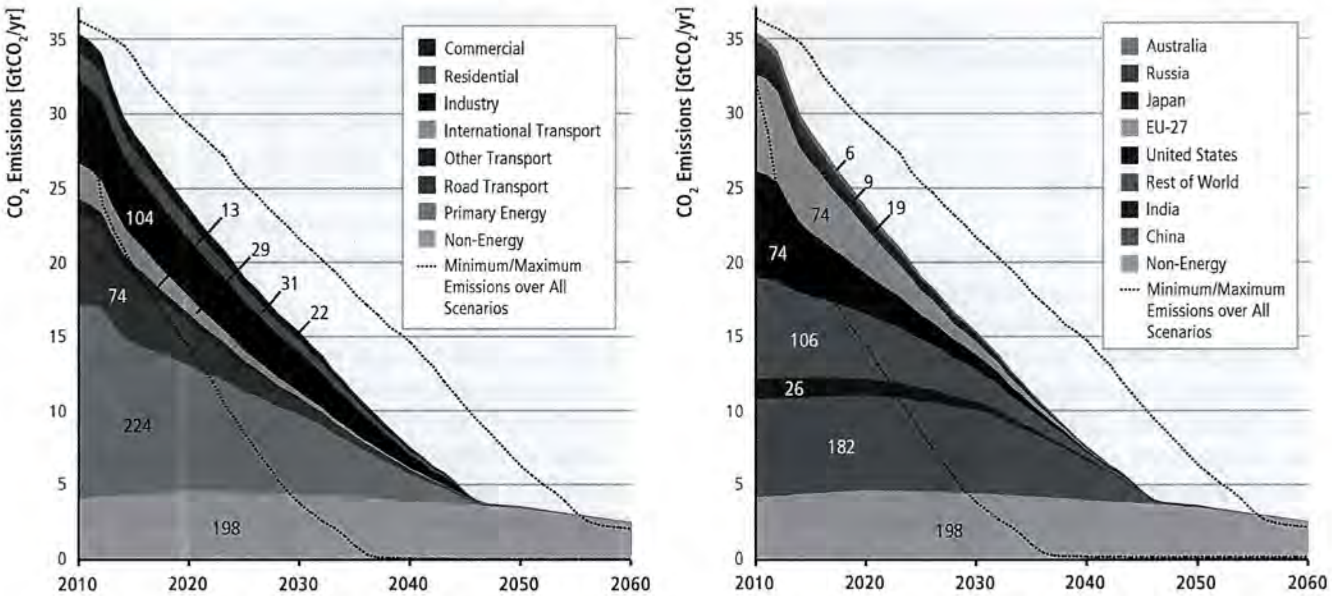


Figure 12.13 | Scenario of CO$_2$ emissions from existing energy and transportation infrastructure by industry sector (left) and country/region (right). Numbers in panels show the cumulated CO$_2$ emissions from 2010 to 2060 in Gt. Source: Davis et al. (2010).

12.4.2 Urban form

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

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

12.4.2.1 Density

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

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

Comparable and consistent estimates of urban densities and changes in urban densities are difficult to obtain in part because of different methodologies to calculate density. However, multiple studies using multiple lines of evidence including satellite data (Deng et al., 2008;

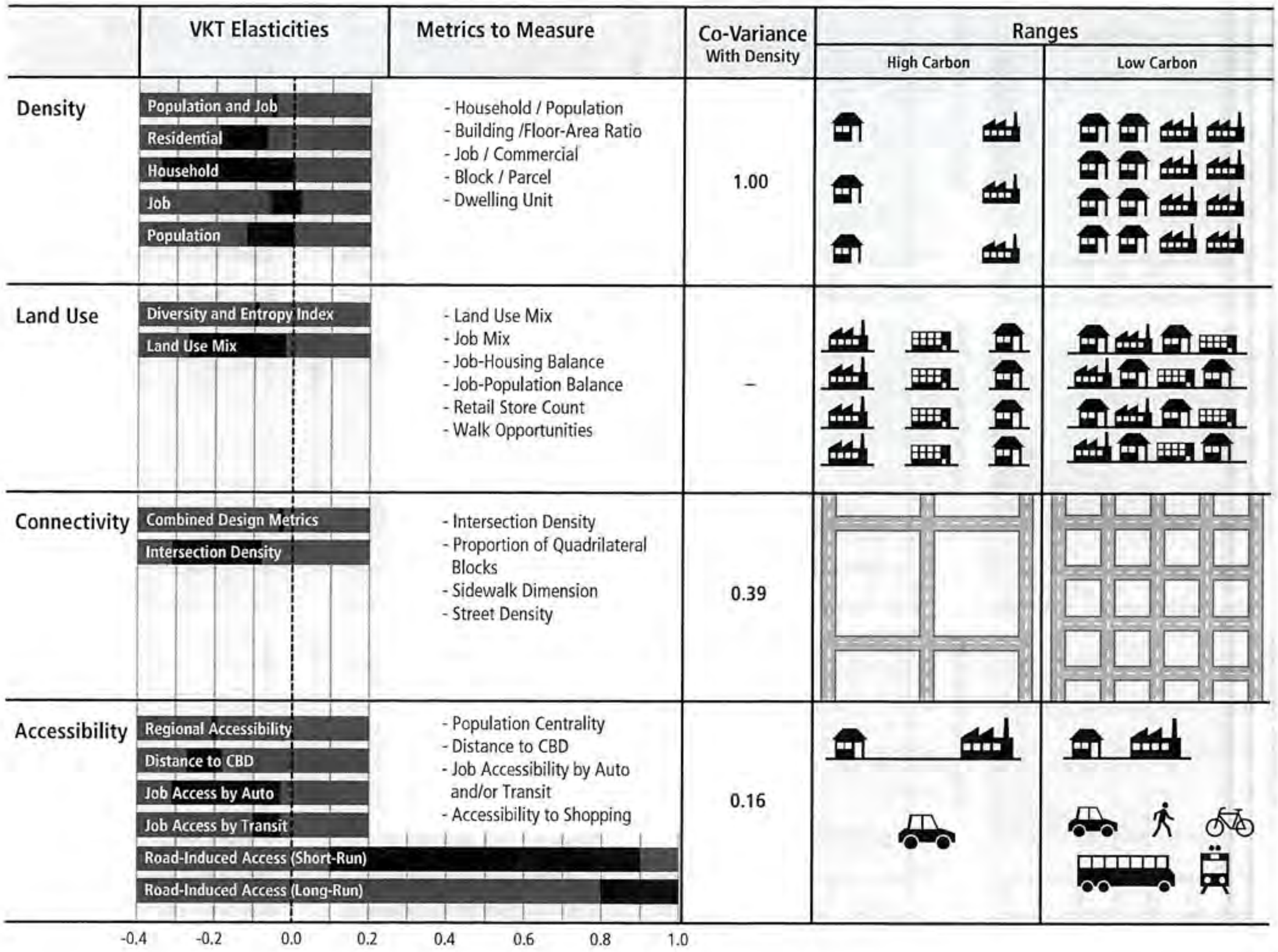


Figure 12.14 | Four key aspects of urban form and structure (density, land use mix, connectivity, and accessibility), their Vehicle Kilometre Travelled (VKT) elasticities, commonly used metrics, and stylized graphics. The dark blue row segments under the VKT elasticities column provide the range of elasticities for the studies included.

Sources: Numbers from Ewing and Cervero (2010), National Research Council (2009a), and Salon et al (2012) are based on the following original sources: **Density** (Schimek, 1996; Kockelman, 1997; Sun et al., 1998; Pickrell and Schimek, 1999; Ewing and Cervero, 2001; Holtzclaw et al., 2002; Bhatia, 2004; Boarnet et al., 2003; Bento et al., 2005; Zhou and Kockelman, 2008; Fang, 2008; Kuzmyak, 2009a; Brownstone and Golob, 2009; Ewing et al., 2009; Greenwald, 2009; Heres-Del-Valle and Niemeier, 2011); **Land Use** (Kockelman, 1997; Sun et al., 1998; Pushkar et al., 2000; Ewing and Cervero, 2001, 2010; Chapman and Frank, 2007; Frank and Engelke, 2005; Kuzmyak et al., 2006; Vance and Hedel, 2007; Brownstone and Golob, 2009; Kuzmyak, 2009b; Frank et al., 2009); **Connectivity** (Ewing and Cervero, 2001; Boarnet et al., 2003; Chapman and Frank, 2007; Frank and Engelke, 2005; Ewing et al., 2009; Greenwald, 2009; Frank et al., 2009); **Accessibility** (Goodwin, 1996; Ewing et al., 1996, 2009; Kockelman, 1997; Cervero and Kockelman, 1997; Sun et al., 1998; Pushkar et al., 2000; Ewing and Cervero, 2001, 2010; Boarnet et al., 2003; Næss, 2005; Cervero and Duncan, 2006; Zegras, 2007; Greenwald, 2009; Kuzmyak, 2009a, b; Frank et al., 2009; Zegras, 2010; Hymel et al., 2010).

Angel et al., 2010, 2011; Seto et al., 2011) and economic and census data (Burchfield et al., 2006) show that both population and built-up densities are declining across all regions around the world (see Section 12.2 for details). Although there is substantial variation in magnitudes and rates of density decline across income groups, city sizes, and regions, the overarching trend is a persistent decline in densities (Angel et al., 2010). The dominant trend is declining density, however there are some exceptions. Analyses of 100 large cities worldwide using a microwave scatterometer show significant vertical expansion of built-up areas in East Asian cities, notably those in China (see Figure 12.15 and Frolking et al., 2013).

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

Medium-rise (less than seven floors) urban areas with a high building footprint ratio can have a higher built density than high-rise urban areas with a low building footprint. These different configurations of high-density development involve important energy tradeoffs. Often, high-rise,

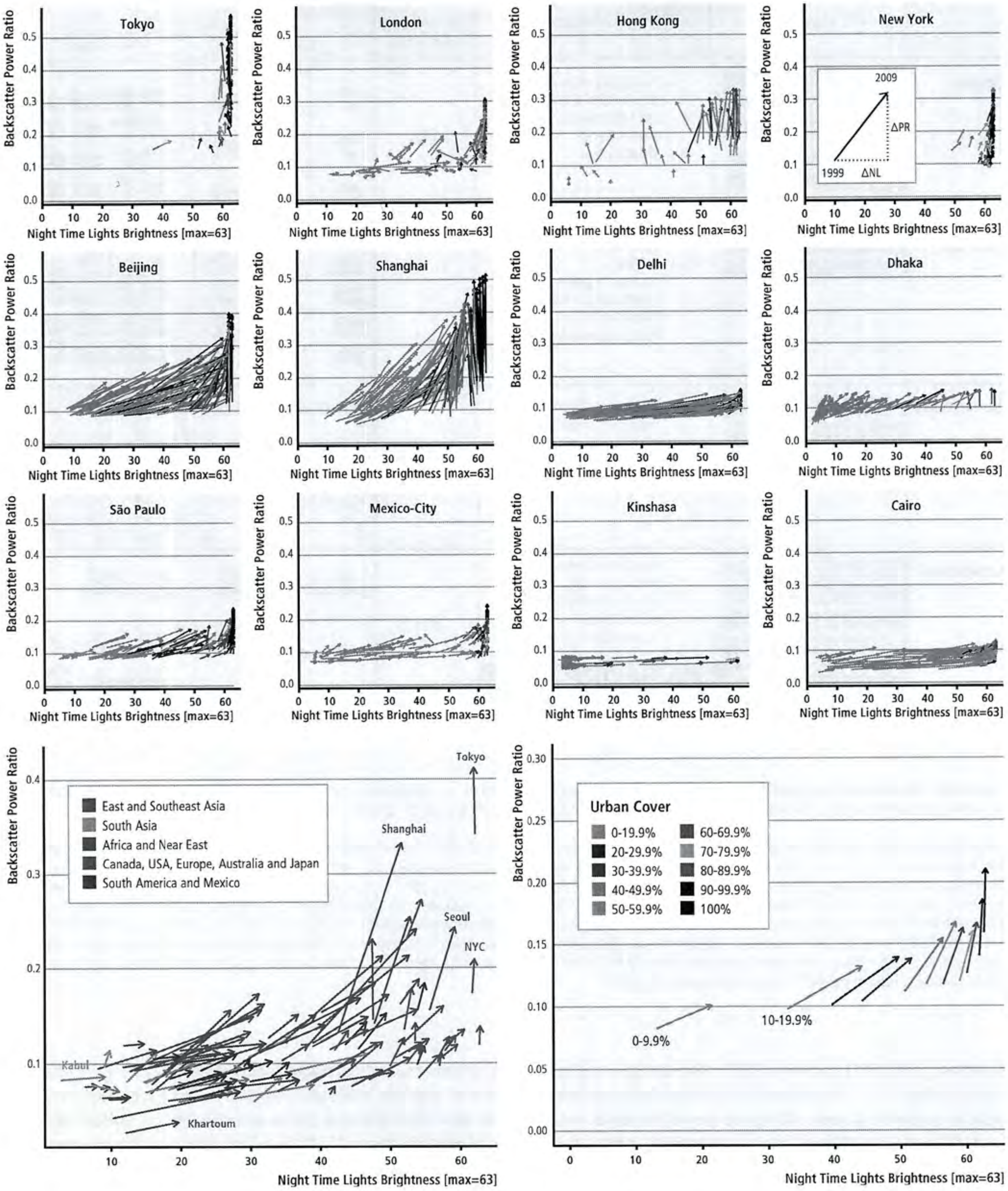


Figure 12.15 | Changes in Urban Structure, 1999–2009 using backscatter and night time lights. The top 12 panels show changes in vertical structure of major urban areas as characterized by backscatter power ratio (PR) and horizontal growth as measured by night time lights brightness (NL) for 12 large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

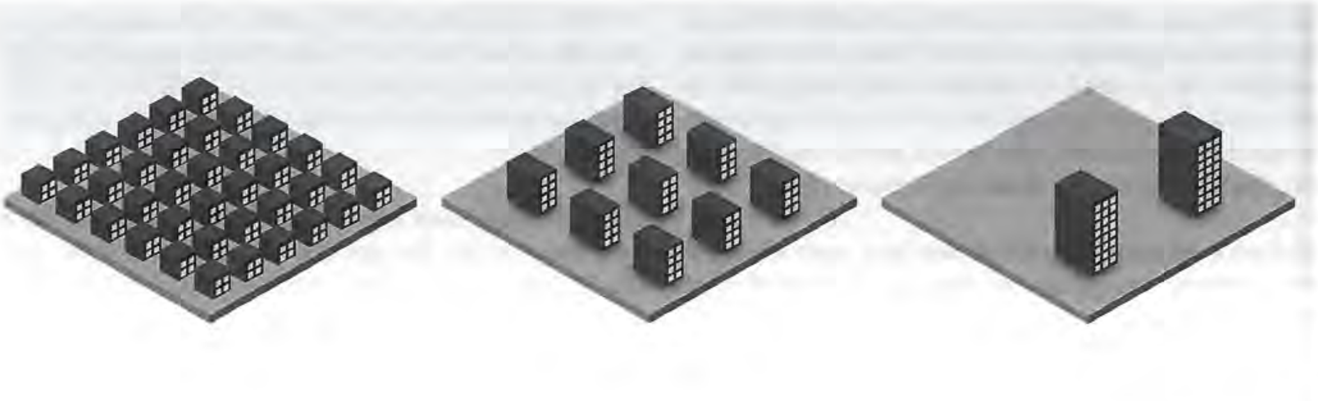


Figure 12.16 | Same densities in three different layouts: low-rise single-story homes (left); multi-story medium-rise (middle); high-rise towers (right). Adapted from Cheng (2009).

high-density urban areas involve a tradeoff between building height and spacing between buildings—higher buildings have to be more spaced out to allow light penetration. High-rise buildings imply higher energy costs in terms of vertical transport and also in heating, cooling, and lighting due to low passive volume ratios (Ratti et al., 2005; Salat, 2009). Medium-rise, high-density urban areas can achieve similar levels of density as high-rise, high density developments but require less materials and embodied energy (Picken and Ilozor, 2003; Blackman and Picken, 2010). Their building operating energy levels are lower due to high passive volume ratio (Ratti et al., 2005; Salat, 2009). Single storey, free-standing housing units are more GHG emissions intensive than multi-family, semi-detached buildings (Myors et al., 2005; Perkins et al., 2009). Thus, while the effect of building type on energy use may be relatively small, the combination of dwelling type, design, location, and orientation together can generate significant energy savings (Rickwood et al., 2008).

12.4.2.2 Land use mix

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

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

At the city-scale, a high degree of land use mix can result in significant reductions in VKT by increasing the proximity of housing to office developments, business districts, shops, and malls (Cervero and Duncan, 2006). In service-economy cities with effective air pollution controls, mixed land use can also have a beneficial impact on citizen health and well-being by enabling walking and cycling (Saelens et al., 2003; Heath et al., 2006; Sallis et al., 2009). For cities with lower mixed land use, such as often found in North American cities and in many new urban develop-

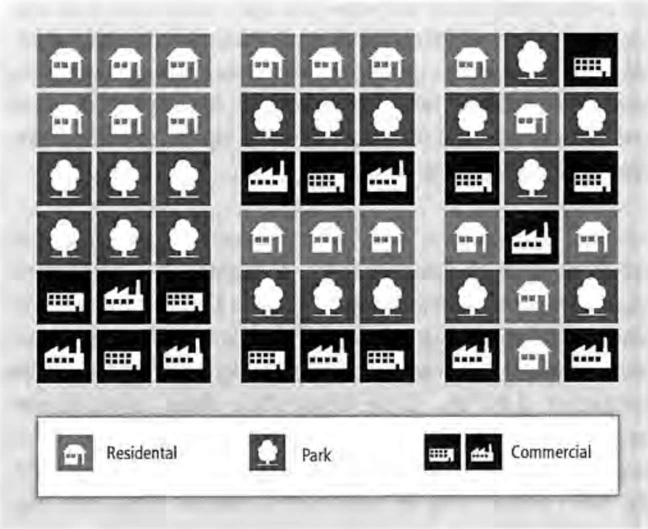


Figure 12.17 | Three different land use mixes (Manaugh and Kreider, 2013).

ments in Asia, large residential developments are separated from jobs or retail centres by long distances. A number of studies of such single-use zoning show strong tendencies for residents to travel longer overall distances and to carry out a higher proportion of their travel in private vehicles than residents who live in mixed land use areas in cities (Mogridge, 1985; Fouchier, 1998; Næss, 2005; Zhou and Kockelman, 2008).

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

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

12.4.2.3 Connectivity

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

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

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

12.4.2.4 Accessibility

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

Countries and regions undergoing early stages of urbanization may therefore have a unique potential to influence accessibility, particularly in cases where income levels, infrastructure, and motorization trends are rapidly changing (Kumar, 2004; Chen et al., 2008; Perkins et al., 2009; Reilly et al., 2009; Zegras, 2010; Hou and Li, 2011; Adeyinka, 2013). In Shanghai, China, new transportation projects have influenced job accessibility and have thereby reduced commute times (Cervero and Day, 2008). In Chennai, India, differences in accessibility to the city centre between low-income communities have been shown to strongly affect transport mode choice and trip frequency (Srinivasan and Rogers, 2005). In the rapidly motorizing city of Santiago de Chile, proximity to the central business district as well as metro stations has a relatively strong association with VKT (Zegras, 2010). The typical elasticity between job accessibility and VKT across

North American cities ranges from –0.10 to –0.30 (Ewing and Cervero, 2010; Salon et al., 2012).

12.4.2.5 Effects of combined options

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

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

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

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

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

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

Market Failures are the result of individuals and firms ignoring the external costs and benefits they impose on others when making economic decisions (see Chapter 15). These include:

- Failure to account for the social costs of GHG (and local) emissions that result from production and consumption activities in cities.
- Failure to account for the social costs of traffic congestion (see Chapter 8).
- Failure to assign property rights and titles for land.
- Failure to account for the social benefits of spatial amenities and mix land uses (see Section 12.5.2.3).
- Failure to account for the social benefits of agglomeration that result from the interactions of individuals and firms in cities.

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

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

Pre-Existing Policies and Regulations can also lead to excessive growth. These include:

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

12.5 Spatial planning and climate change mitigation

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

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

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

12.5.1 Spatial planning strategies

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

12.5.1.1 Macro: Regions and metropolitan areas

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

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

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

Regional jobs-housing balance. Separation of workers from job sites creates long-haul commutes and thus worsens traffic and environmental conditions (Cervero, 1996). Jobs-housing imbalances are often a product of insufficient housing in jobs-rich cities and districts (Boarnet and Crane, 2001; Wilson, 2009; Pendall et al., 2012). One view holds that the market will eventually work around such problems–developers will build more housing near jobs because more profit can be made from such housing

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

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

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

(Gordon et al., 1991; Downs, 2004). There is evidence of co-location in US cities like Boston and Atlanta (Weitz, 2003). Even in the developing world, co-location occurs as a means to economize on travel, such as the peri-urban zones of Dar es Salaam and Lagos where infill and densification, often in the form of informal settlements and shantytowns, occurs in lieu of extended growth along peripheral radial roads (Pirie, 2011).

Research on balanced growth strategies provides mixed signals on mobility and environmental impacts. Studies of Atlanta estimate that jobs-housing balance can reduce traffic congestion, emissions, and related externalities (Weitz, 2003; Horner and Murray, 2003). In the San Francisco Bay Area, jobs-housing balance has reduced travel more than intermixing housing and retail development (Cervero and Duncan, 2006). Other studies, however, suggest that jobs-housing balance has little impact on travel and traffic congestion since many factors besides commuting condition residential location choices (Levine, 1998).

Self-contained, 'complete' communities—wherein the jobs, retail commodities and services needed by workers and households exist within a community—is another form of balanced growth. Many master-planned new towns in the United States, France, South Korea, and the UK were designed as self-contained communities, however their physical isolation and economic dependence on major urban centres resulted in high levels of external motorized travel (Cervero, 1995b; Hall, 1996).

How new towns are designed and the kinds of transport infrastructure built, experiences show, have strongly influenced travel and environmental outcomes (Potter, 1984). In the UK, new towns designed for good transit access (e.g., Runcorn and Redditch) averaged far higher transit ridership and less VKT per capita than low-density, auto-oriented communities like Milton Keynes and Washington, UK (Dupree, 1987).

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

12.5.1.2 Meso: Sub-regions, corridors, and districts

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

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

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

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

12.5.1.3 Micro: communities, neighbourhoods, streetscapes

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

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

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

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

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

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

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

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

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

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

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

12.5.2 Policy instruments

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

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

12.5.2.1 Land use regulations

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

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

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

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

Building codes provide a mechanism to regulate the energy efficiency of development. Building codes affect the energy efficiency of new development, and cities provide enforcement of those regulations in some countries (Chapter 9). City policies influence emissions through energy use in buildings in several other ways, which can influence purchases and leasing of commercial and residential real estate properties. Some cities participate in energy labelling programmes for buildings (see Chapter 9.10.2.6) or have financing schemes linked to property taxes (see Property Assess Clean Energy (PACE) in Chapter 9.10.3.1). Energy efficient equipment in buildings can further reduce

Box 12.4 | What drives declining densities?

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

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

energy consumption and associated emissions, including electronics, appliances, and equipment (see Table 9.3). Cities that operate utilities can influence energy usage directly by using smart meters and information infrastructures (see 9.4.1.3).

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

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

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

12.5.2.2 Land management and acquisition

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

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

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

12.5.2.3 Market-based instruments

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

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

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

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

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

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

Box 12.5 | Singapore: TOD and Road Pricing

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

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

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

Empirically, evidence for this relationship comes from cities in the United States, where a 10% increase in fuel prices leads to a 10% decrease in construction on the urban periphery (Molloy and Shan, 2013); Canada,

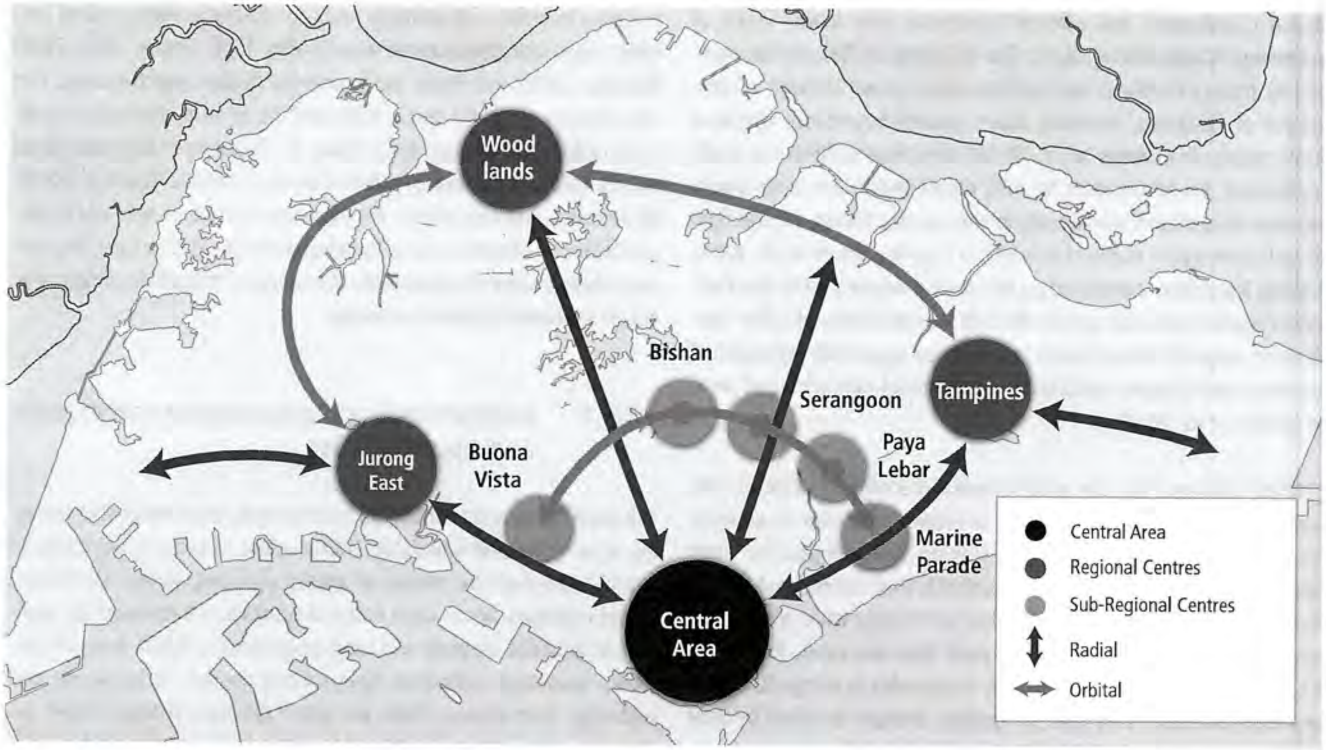


Figure 12.18 | Singapore's Constellation Plan. Source: Suzuki et al. (2013).

where a 1 % increase in gas prices is associated with a 0.32 % increase in the population living in the inner city (Tanguay and Gingras, 2012); and cross-national datasets of 35 world cities (Glaeser et al., 2001; Glaeser and Kahn, 2004). However, another cross-national study using a larger dataset found no statistically significant link, which the authors attribute to noisiness in their (national-level) fuel price data (Angel et al., 2005).

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

12.5.3 Integrated spatial planning and implementation

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

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

12.6 Governance, institutions, and finance

The feasibility of spatial planning instruments for climate change mitigation depends greatly upon each city's governance and financial capacities. Even if financial capacities are present, a number of other obstacles need to be surmounted. For example, many local governments are disinclined to support compact, mixed-use, and dense development. Even in cases where there is political support for low-carbon development, institutions may be ineffective in developing, implementing, or regulating land use plans. This section assesses the governance, institutional, and financial challenges and opportunities for implementing the mitigation strategies outlined in Section 12.5. It needs to be emphasized that both the demand for energy and for urban infrastructure services, as well as the efficiency of service delivery, is also influenced by behaviour and individual choices. Cultural and lifestyle norms surrounding comfort, cleanliness, and convenience structure expectations and use of energy, water, waste, and other urban infrastructure services (Miller, 1998; Shove, 2003, 2004; Bulkeley, 2013). Individual and household choices and behaviour can also strongly affect the demand for, and the delivery efficiency of, public infrastructure services, for instance by lowering or increasing load factors (utilization rates) of public transport systems (Sammer, 2013). Governance and institutions are necessary for the design and implementation of effective policy frameworks that can translate theoretical emission reduction potentials of a range of mitigation options into actual improved emission outcomes.

12.6.1 Institutional and governance constraints and opportunities

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

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

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

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

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

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

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

Box 12.6 | Sustainable Curitiba: Visionary planning and strong institutions

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

However, urban governance of land use and transport planning is not the sole province of municipal authorities or other levels of government. Increasingly, private sector developers are creating their own strategies to govern the nature of urban development that exceed codes and established standards. These strategies can relate both to the physical infrastructure being developed (e.g., the energy rating of housing on a particular development) or take the form of requirements and guides for those who will occupy new or refurbished developments (e.g., age limits, types of home appliance that can be used, energy contracts, and education about how to reduce GHG emissions). Non-governmental organizations (NGOs) aimed at industry groups, such as the U.S. Green Building Council, the Korea Green Building Certification Criteria, and UK's Building Research Establishment Environmental Assessment Method (BREEAM) have also become important in shaping urban development, particularly in terms of regeneration and the refurbishment or retrofitting of existing buildings. For example, this is the case in terms of community-based organizations in informal settlements, as well as in the redevelopment of brownfield sites in Europe and North America.

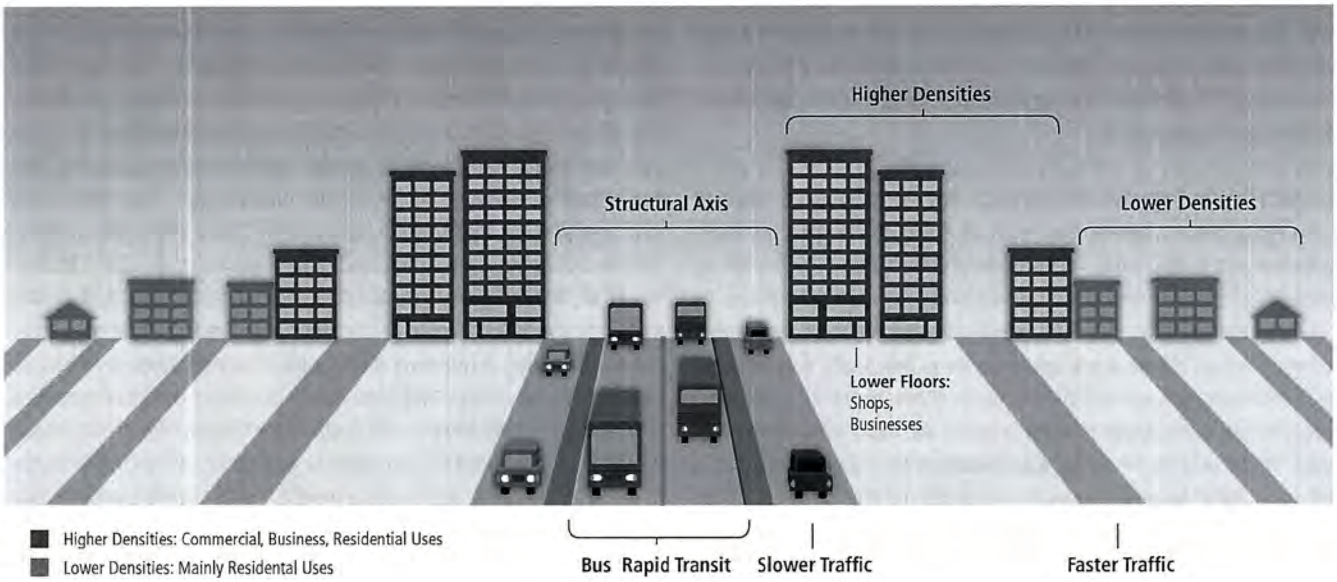


Figure 12.19 | Curitiba's stylized trinary road system. The inclusion of mixed land uses and affordable housing allows developers to increase building heights, adding density to the corridor. Source: Suzuki et al. (2013).

12.6.2 Financing urban mitigation

Urban infrastructure financing comes from a variety of sources, some of which may already be devoted to urban development. Some of these include direct central government budgetary investments, intergovernmental transfers to city and provincial governments, revenues raised by city and provincial governments, the private sector or public-private partnerships, resources drawn from the capital markets via municipal bonds or financial intermediaries, risk management instruments, and carbon financing. Such sources provide opportunities for urban mitigation initiatives (OECD, 2010b), but access to these financial resources varies from one place to another.

In many industrialized countries, national and supra-national policies and programmes have provided cities with the additional financing and facilitations for urban climate change mitigation. Where the national commitment is lacking, state and municipal governments can influence mitigation initiatives at the city scale. Cities in emerging economies are also increasingly engaging in mitigation, but they often rely on international sources of funding. GHG abatement is generally pursued as part of the urban development efforts required to improve access to infrastructure and services in the fast-growing cities of developing countries, and to increase the liveability of largely built-out cities in industrialized countries. Incorporating mitigation into urban development has important financial implications, as many of the existing or planned urban investments can be accompanied through requirements to meet certain mitigation standards (OECD, 2010b). As decentralization has progressed worldwide (the average share of sub-national expenditure in OECD countries reached 33 % in 2005), regional and local governments increasingly manage significant resources.

Local fiscal policy itself can restrict mitigation efforts. When local budgets rely on property taxes or other taxes imposed on new development, there is a fiscal incentive to expand into rural areas or sprawl instead of pursuing more compact city strategies (Ladd, 1998; Song and Zenou, 2006). Metropolitan transportation policies and taxes also affect urban carbon emissions. Congestion charges reduce GHG emissions from transport by up to 19.5 % in London where proceeds are used to finance public transport, thus combining global and local benefits very effectively (Beevers and Carslaw, 2005). Parking charges have led to a 12 % decrease of vehicle miles of commuters in U.S. cities, a 20 % reduction in single car trips in Ottawa, and a 38 % increase of carpooling in Portland (OECD, 2010c).

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

Fiscal crises along with public investment, urban development, and environmental policy challenges in both developed and developing counties have sparked interest in innovative financial instruments to affect spatial development, including a variety of land-based techniques (Peterson, 2009). One of these key financial/economic mechanisms is land value capture. Land value capture consists of financing the construction of new transit infrastructures using the profits generated by the land value price increase associated with the presence of new infrastructure (Dewees, 1976; Benjamin and Sirmans, 1996; Batt, 2001; Fensham and Gleeson, 2003; Smith and Gihring, 2006). Also called windfall recapture, it is a local financing option based on recouping a portion or all of public infrastructure costs from private land betterments under the 'beneficiary' principle. In contrast, value compensation, or wipeout mitigation, is commonly viewed as a policy tool to alleviate private land worsements—the deterioration in the value or usefulness of a piece of real property—resulting from public regulatory activities (Hagman and Misczynski, 1978; Callies, 1979).

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

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

12.7 Urban climate mitigation: Experiences and opportunities

This section identifies the scale and range of mitigation actions being planned by municipal governments and assesses the evidence of successful implementation of the plans as well as barriers to further implementation. The majority of studies reviewed pertain to large

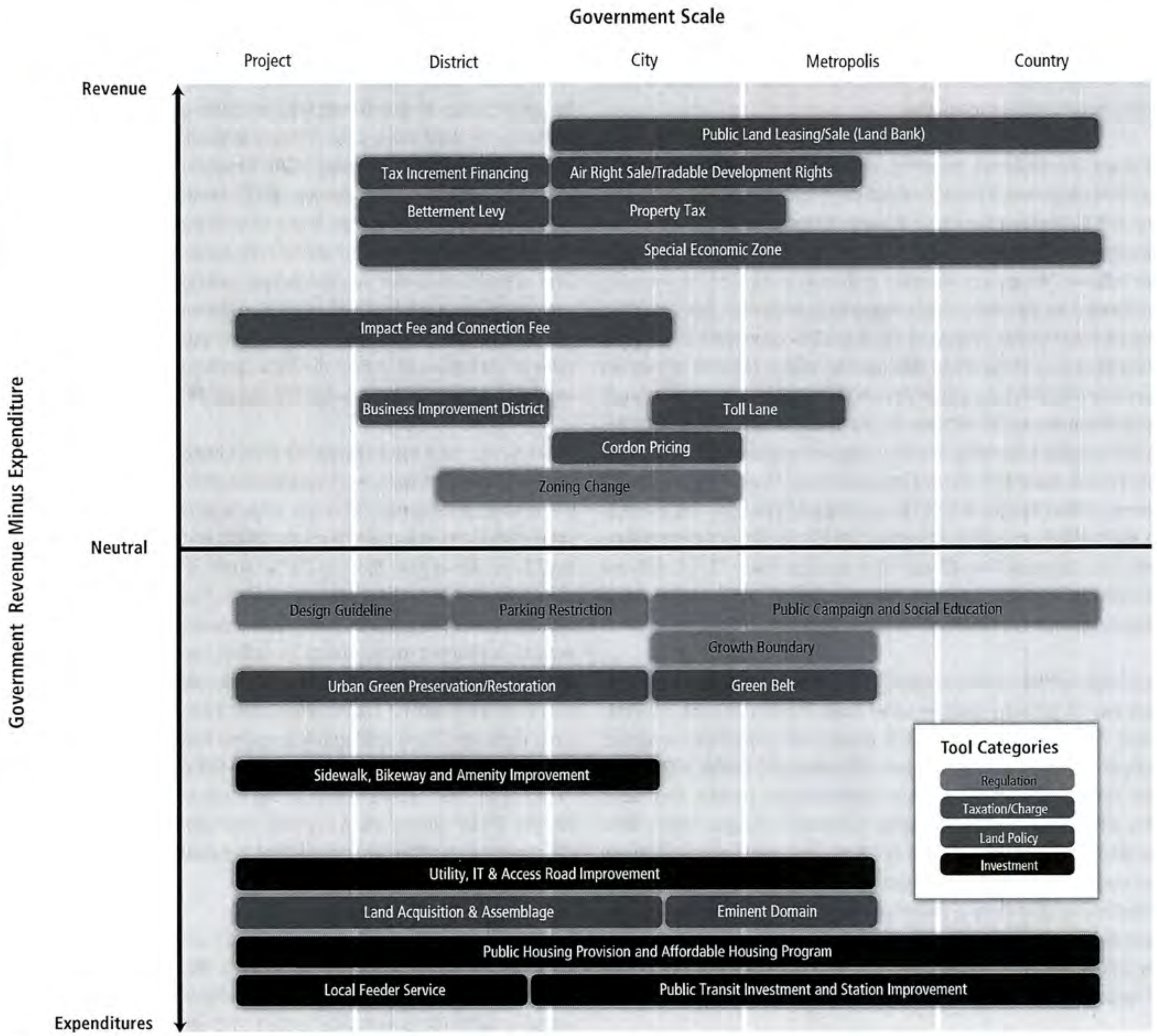


Figure 12.20 | Key spatial planning tools and effects on government revenues and expenditures across administrative scales. Figure shows four key spatial planning tools (coded in colours) and the scale of governance at which they are administered (x-axis) as well as how much public revenue or expenditure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

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

cities in North America, Japan, and Europe, although there are some cross-city comparisons and case studies that include smaller cities in industrialized economies (Yalçın and Lefèvre, 2012; Dierwechter and Wessells, 2013) and cities in developing countries and emerging economies (Romero Lankao, 2007; Pitt, 2010).

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

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

12.7.1 Scale of urban mitigation efforts

The number of cities that have signed up to voluntary frameworks for GHG emission reductions has increased from fewer than 50 at the start of the 1990s to several hundred by the early 2000s (Bulkeley and Betsill, 2005), and several thousand by 2012 (Kern and Bulkeley, 2009; Pitt, 2010; Krause, 2011a). These voluntary frameworks provide technical assistance and political visibility. They include the C40 Cities Climate Leadership Group (C40), which by October 2013 counted most of the world's largest cities among its 58 affiliates (C40 Cities, 2013), the Cities for Climate Protection (CCP) Campaign, and the 2013 European Covenant of Mayors, which had over 5,200 members representing over 170 million people, or roughly one-third of the European population (The Covenant of Mayors, 2013). In the United States, nearly 1,100 municipalities, representing approximately 30 % of the country's population, have joined the U.S. Conference of Mayors Climate Protection Agreement, thus committing to reduce their local GHG emissions to below 1990 levels (Krause, 2011a).

Such estimates represent a lower bound, as cities may complete a climate action plan or undertake mitigation outside one of these voluntary frameworks. In California in 2009, 72 % of cities responding

Box 12.7 Urban climate change mitigation in less developed countries

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

Urban areas in developing and least developed countries can have dual energy systems (Martinot et al., 2002; Berndes et al., 2003). That is, one segment of the population may have access to modern energy and associated technology for heating and cooking. Another segment of the population—mainly those living in informal settlements—may rely mainly on wood-based biomass. Such non-commercial biomass is a prominent source in the urban fuel mix in Sub-Saharan Africa (50 %) and in South Asia (23 %). In other regions, Latin America and the Caribbean (12 %), Pacific Asia (8 %) and China (7 %) traditional, non-commercial energy is not negligible but a relatively smaller proportion of overall energy portfolio (Grubler et al., 2012). The traditional energy system operates informally and inefficiently, using out-dated technology. It can be associated with significant health impacts (see Section 9.7.3 in this report as well as Chapters 2 and 9 in IPCC, 2011). The unsustainable harvesting of woodfuels to supply large urban and industrial markets is significantly contributing to forest degradation and coupled with other land-use changes to deforestation (see Chapter 11). However, recent technological advances suggest that energy production from biomass can be an opportunity for low carbon development (Zeng et al., 2007; Fargione et al., 2008; Hoekman, 2009; Azar et al., 2010). Projections of significant growth in woodfuel demand (Mwampamba, 2007; Zulu, 2010; Agyeman et al., 2012) make it vital that this sector is overhauled and modernized using new technologies, approaches, and governance mechanisms.

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

to a survey stated they had adopted policies and/or programmes to address climate change, but only 14 % had adopted a GHG reduction target (Wang, 2013). In some countries, climate action plans are mandatory for local governments, further adding to the total. For example, in Japan, the Global Warming Law and the Kyoto Protocol Target Achievement Plan mandate that 1,800 municipal governments and 47 Prefectures prepare climate change mitigation action plans (Sugiyama and Takeuchi, 2008). In France, climate action plans are mandatory for cities with populations larger than 50,000 (Yalçın and Lefèvre, 2012). Climate action planning has been most extensive in cities in Annex I countries, particularly those in Europe and Japan. This presents a mismatch between the places with mitigation planning efforts and the places where most urban growth will occur—and where the greatest mitigation potential exists—largely in developing countries that are rapidly urbanizing.

12.7.2 Targets and timetables

One way to assess the scale of planned mitigation is through the emission reduction targets set by cities, typically as part of their climate action plans. A central feature of municipal climate change responses is that targets and timetables have frequently exceeded national and international ambitions for emissions reduction. In Germany, nearly 75 % of cities with a GHG target established their emissions goals based on national or international metrics rather than on a local analysis of mitigation options and the average city reduction target of 1.44 % per year exceeds the national target (Sippel, 2011). In the United States, signatories to the Mayors Climate Protection Agreement have pledged to reduce GHG emissions by 7 % below 1990 levels by 2012, in line with the target agreed upon in the Kyoto Protocol for the United States (Krause, 2011b). Lutsey and Sperling (2008) find that these and other targets in 684 U.S. cities would reduce total emissions in the United States by 7 % below the 2020 business-as-usual (BAU) baseline.

In Europe and Australia, several municipalities have adopted targets of reducing GHG emissions by 20 % by 2020 and long-term targets for radically reducing GHG emissions, including 'zero-carbon' targets in the City of Melbourne and Moreland (Victoria), and a target of 80 % reduction over 1990 levels by 2050 in London (Bulkeley, 2009). This approach has not been limited to cities in developed economies. For example, the city of Cape Town has set a target of increasing energy efficiency within the municipality by 12 % by 2010 (Holgate, 2007), and Mexico City has implemented and achieved a target of reducing 7 million tons of GHG from 2008 to 2012 (Delgado-Ramos, 2013). Data compiled for this assessment, although illustrative rather than systematic, indicate an average reduction of 2.74 t CO_2eq/cap if cities were to achieve their targets, with percentage targets ranging from 10 % to 100 %. In general, percentage reduction targets are larger for more distant years and in more affluent cities. However, the absolute level of the targeted reductions depends primarily on the city's population and other determinants of baseline emissions (Figure 12.21.).

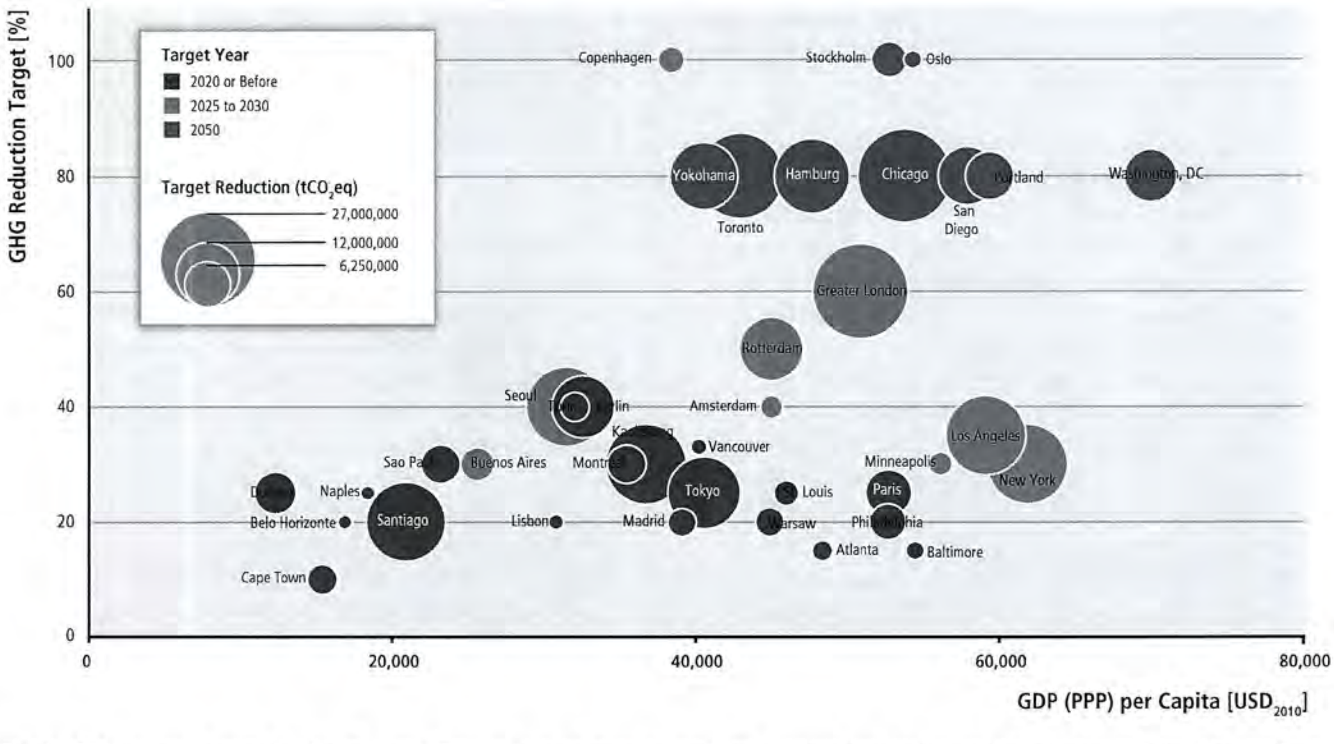


Figure 12.21 | Mitigation targets for 42 cities. Sources: Baseline emissions, reduction targets, and population from self-reported data submitted to Carbon Disclosure Project (2013). GDP data from Istrate & Nadeau (2012). Note that the figure is illustrative only; data are not representative, and physical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

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

Many cities, particularly those in developing countries, do not set targets at all. For example, the Delhi Climate Change Agenda only reports Delhi's CO_2 emissions from power, transport, and domestic sectors as 22.49 $MtCO_2$ for 2007—2008 (Government of NCT of Delhi, 2010), while the contributions from commercial sectors and industries comprise a larger share of the city's total emissions. Furthermore, Delhi's climate action plan lacks clear GHG reduction targets, an analysis of the total carbon reductions projected under the plan, and a strategy for how to achieve their emissions goals. Similar limitations are apparent in mitigation plans for other global cities such as Bangkok and Jakarta (Dhakal and Poruschi, 2010). For many cities in developing countries, a reliable city GHG inventory may not exist, making the climate change actions largely symbolic. However, these city action plans provide a foundation for municipal engagement in mitigation initiatives while building momentum for collective action on a global scale.

12.7.3 Planned and implemented mitigation measures

Limited information is available on the extent to which targets are being achieved or emissions reduced. Some cities have already achieved their initial GHG reduction targets, e.g., Seattle (Boswell et al., 2011), or are on track to do so, e.g. Stockholm (City of Stock-

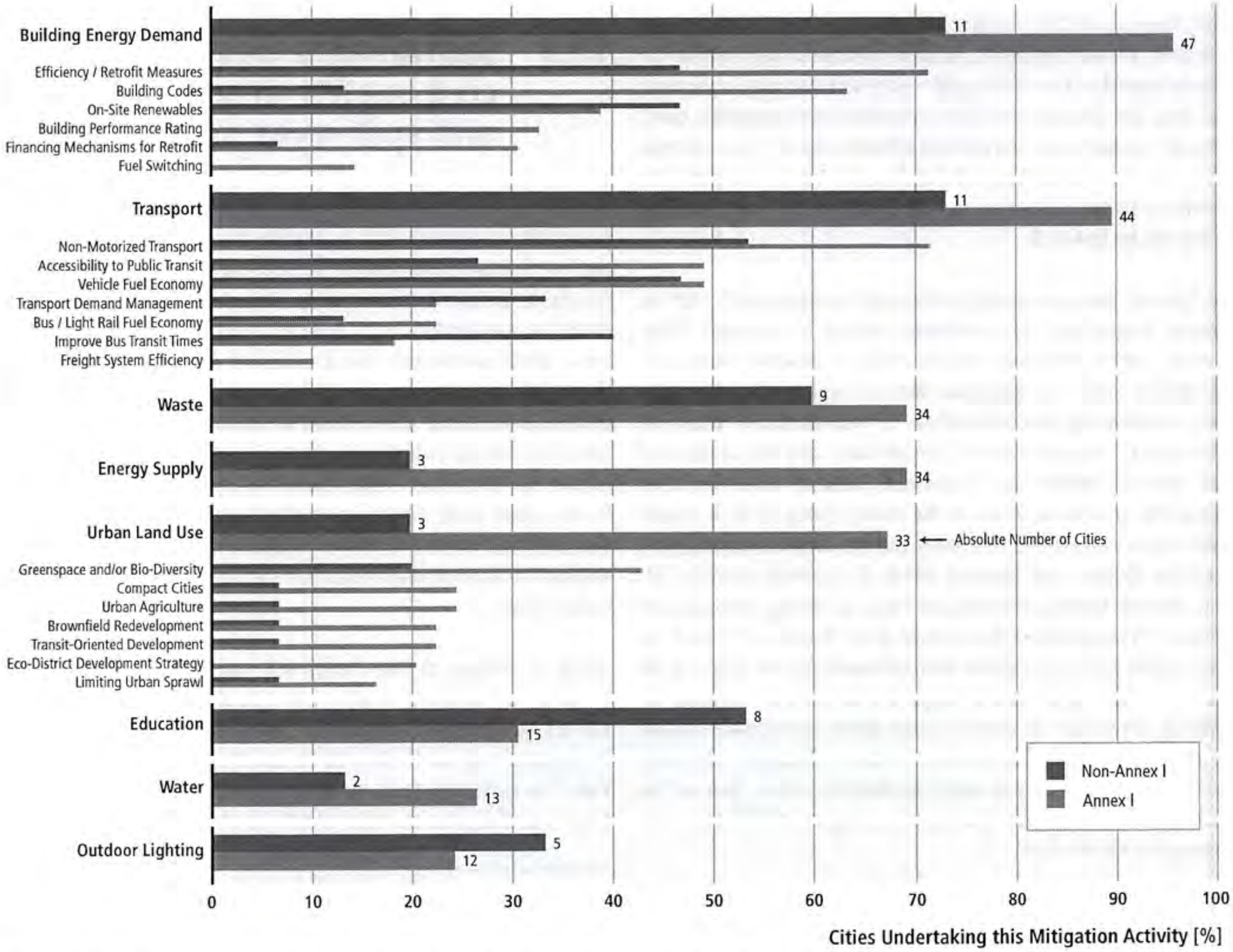


Figure 12.22 | Mitigation measures in climate action plans. Sources: Compiled for this assessment from self-reported data submitted to Carbon Disclosure Project (2013).

holm, 2013). In other places such as western Germany, few if any cities are likely to meet their targets (Sippel, 2011). Further data come from comparison of 'before' and 'after' GHG inventories. One study of six major cities found that emissions are falling by an average 0.27 t CO_2eq/cap per year (Kennedy et al., 2012). Overall, however, the available data are usually incomplete, self-reported, and subject to various biases. More fundamentally, changes in aggregate emissions do not necessarily reflect the success or failure to implement mitigation measures, because so many drivers of emissions—including the electricity generation mix and fuel taxation—are normally beyond the control of cities (DeShazo and Matute, 2012). Whether a city achieves its target has less to do with its own actions and more to do with external drivers of emissions.

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

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

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

Despite the implementation of comprehensive climate action plans and policies, progress for cities in developed countries is slow and the achievability of emissions targets remains uncertain. Although municipalities often highlight progress on mitigation projects, the impacts of these initiatives are not often evaluated (see Chapter 15 on policy evaluation). Cities' mitigation reduction performance is largely correlated to the national performance in mitigation reduction.

12.8 Sustainable development, co-benefits, trade-offs, and spill-over effects

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

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

---

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

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

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

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

the modern world: this section will focus on the literature specifically linked to urban settings and refer to other sections of the report where appropriate.

Action on climate change mitigation often depends on the ability to 'reframe' or 'localize' climate change with respect to the co-benefits that could be realized (Betsill, 2001). For example, in Canada "actions to reduce GHG emissions are also deeply connected to other goals and co-benefits such as human health improvements through improved air quality, cost savings, adaptability to real or potential vulnerabilities due to climate change, and overall improvements in short, medium and long-term urban sustainability" (Gore et al., 2009). Sometimes called 'localizing' or 'issue bundling' (Koehn, 2008), these reframing strategies have proven to be successful in marshalling local support and action in developing country cities, and will continue to be an important component of developing local capacity for mitigation (Puppim de Oliveira, 2009).

12.8.1 Urban air quality co-benefits

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

Major air quality co-benefits can be achieved through mitigation actions in the urban context, especially in megacities in developing countries where outdoor air pollution tends to be higher than in urban centres in industrialized countries (Molina and Molina, 2004 and section 5.7). Urban planning strategies and other policies that promote cleaner fuels, transport mode shifting, energy cogeneration and waste heat recycling, buildings, transport and industry efficiency standards can all contribute to lower rates of respiratory and cardiovascular disease (improved human health) as well as decreased impacts on urban vegetation (enhanced ecosystems) via simultaneous reductions in co-emitted air pollutant species (Campbell-Lendrum and Corvalán, 2007; Creutzig and He, 2009; Milner et al., 2012; Puppim de Oliveira et al., 2013 and Sections 7.9, 8.7, 9.7, 10.8 as well as WGII AR5 Chapter 11.9).[4] Even an action like shading parking lots, which is generally thought of in the context of limiting the urban heat-island effect, can bring air pollution co-benefits through reductions in volatile organic compounds (VOC) and, thus, low-level ozone formation from parked vehicles (Scott et al., 1999).

---

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

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

12.8.2 Energy security side-effects for urban energy systems

Mitigating climate change could have important side-effects for urban energy security (sufficient resources and resilient supply)—concerns that have re-emerged in many cities throughout the world in recent years (see Sections 6.6.2.1 and 7.9.1 for a broader discussion of energy security concerns). Perhaps the greatest energy-related vulnerability in this context is the fact that urban transport systems are at present almost entirely dependent on oil (Cherp et al., 2012). This is especially true in low-density areas where reliance on private vehicles is high (Levinson and Kumar, 1997). Therefore, any mitigation activities leading to a diversification of the transport sector away from oil could potentially also contribute to a security co-benefit (see Jewell et al., 2013 and other references in Chapter 8.7.1). Such measures might range from technology standards (e.g., for vehicles and their fuels) to integrated infrastructure, spatial planning, and mass transit policies (Sections 12.5 and 8.10). Energy efficiency regulations for buildings and industrial facilities (both existing and new) can also help to enhance the resilience of fuel and electricity distribution networks (see Chapters 9.7 and 10.8).

12.8.3 Health and socioeconomic co-benefits

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

Neighbourhoods with walkable characteristics such as connectivity and proximity of destinations are correlated with higher frequency of physical activity among residents (Frank et al., 2004; Owen et al., 2007), which is correlated with lower symptoms and incidences of depression (Galea et al., 2005; Berke et al., 2007; Duncan et al., 2013).

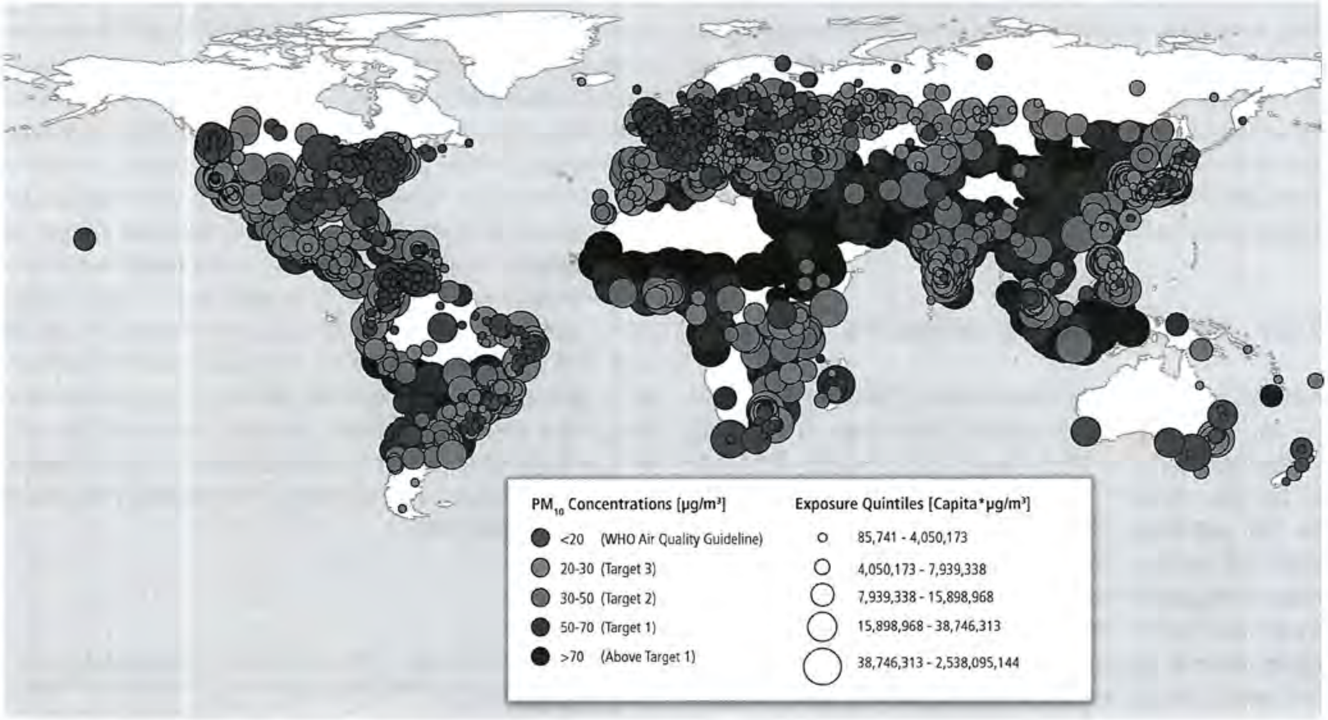


Figure 12.23 | Human risk exposure to PM_{10} pollution in 3200 cities worldwide. Source: Grubler et al.(2012) based on Doll (2009) and Doll and Pachauri (2010).

Compact neighbourhoods with more diversified land uses are correlated with higher housing prices and rents (Mayer and Somerville, 2000; Quigley and Raphael, 2005; Glaeser et al., 2006; Koster and Rouwendal, 2012). In a study of the Netherlands, neighbourhoods with more diverse land uses had a 2.5 % higher housing prices (Koster and Rouwendal, 2012).

12.8.4 Co-benefits of reducing the urban heat island effect

The urban heat island (UHI) effect presents a major challenge to urban sustainability (see WG II AR5 Chapter 8). Not only does UHI increase the use of energy for cooling buildings (and thus increasing the mitigation challenge) and thermal discomfort in urban areas, but UHI also increases smoggy days in urban areas, with smog health effects present above 32 °C (Akbari et al., 2001; O'Neill and Ebi, 2009; Mavrogianni et al., 2011; Rydin et al., 2012). Proven methods for cooling the urban environment include urban greening, increasing openness to allow cooling winds (Smith and Levermore, 2008), and using more 'cool' or reflective materials that absorb less solar radiation, i.e., increasing the albedo of the surfaces (Akbari et al, 2008; Akbari and Matthews, 2012). Reducing UHI is most effective when considered in conjunction with other environmental aspects of urban design, including solar/daylight control, ventilation and indoor environment, and streetscape (Yang et al., 2010). On a global scale, increasing albedos of urban roofs and paved surfaces is estimated to induce a negative radiative forcing equivalent to offsetting about 44 Gt of CO_2 emissions (Akbari et al., 2008).

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

The projected global mean surface temperature increases under climate change will disproportionally impact cities already affected by UHI, thereby increasing the energy requirements for cooling buildings and increasing urban carbon emissions, as well as air pollution (Mickley et al., 2004; Jacob and Winner, 2009). In addition, it is likely that cities will experience an increase in UHI as a result of projected increases in global mean surface temperature under climate change, which will result in additional global urban energy use, GHG emissions, and local air pollution. As reviewed here, studies indicate that several strategies are effective for decreasing the UHI. An effective strategy to mitigate UHI through increasing green spaces, however, can potentially conflict with a major urban climate change mitigation strategy, which is increasing densities to create more compact cities (Milner et al., 2012). This conflict illustrates the complexity of developing integrated and effective climate change policies for urban areas.

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

12.9 Gaps in knowledge and data

This assessment highlights a number of key knowledge gaps:

- **Lack of consistent and comparable emissions data at local scales.** Although some emissions data collection efforts are underway, they have been undertaken primarily in large cities in developed countries. The lack of baseline data makes it particularly challenging to assess the urban share of global GHG emissions as well as develop urbanization and typologies and their emission pathways. Given the small number of city based estimates, more city data and research are needed, especially an urban emissions data system.

- **Little scientific understanding of the magnitude of the emissions reduction from altering urban form, and the emissions savings from integrated infrastructure and land use planning.** Furthermore, there is little understanding of how different aspects of urban form interact and affect emissions. The existing research on the impact of policies designed to achieve emissions reductions through urban form do not conform to the standards of policy evaluation and assessment defined in Chapter 15.

- **Lack of consistency and thus comparability on local emissions accounting methods.** Different accounting protocols yield significantly different results, making cross-city comparisons of emissions or climate action plans difficult. There is a need for standardized methodologies for local- or urban-level carbon accounting.

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

- **Lack of scientific understanding of how cities can prioritize climate change mitigation strategies, local actions, investments, and policy responses that are locally relevant.** Some cities will be facing critical vulnerability challenges, while other will be in the 'red zone' for their high levels of emissions. Local decision-makers need clarity on where to focus their actions, and to avoid spending resources and efforts on policies and investments that are not essential. There is little scientific basis for identifying the right mix of policy responses to address local and urban level mitigation and adaptation. Policy packages will be determined based on the characteristics of individual cities and their urbanization and development pathways, as well as on forecasts of future climate and urbanization. They will be aimed at flexing the urban- and settlement-related 'drivers' of emissions and vulnerability in order to ensure a less carbon-intensive and more resilient future for cities.

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

12.10 Frequently Asked Questions

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

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

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

The exact share of urban energy and GHG emissions varies with emission accounting frameworks and definitions. Urban areas account for 67–76 % of global energy use and 71–76 % of global energy-related CO_2 emissions. Using Scope1 accounting, urban share of global CO_2 emissions is about 44 %.

Urban areas account for between 53 % and 87 % (central estimate, 76 %) of CO_2 emissions from global final energy use and between 30 % and 56 % (central estimate, 43 %) of global primary energy related CO_2 emissions.

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

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

References

Aall C., K. Groven, and G. Lindseth (2007). The Scope of Action for Local Climate Policy: The Case of Norway. *Global Environmental Politics* **7**, 83–101. doi: 10.1162/glep.2007.7.2.83.

Acuto M. (2013). The new climate leaders? *Review of International Studies* **39**, 835–857. doi: 10.1017/S0260210512000502.

Adeyinka A.M. (2013). Spatial Distribution, Pattern and Accessibility of Urban Population to Health Facilities in Southwestern Nigeria: The Case Study of Ilesa. *Mediterranean Journal of Social Sciences* **4**, 425–436. ISSN: 2039-2117. doi: 10.5901/mjss.2013.v4n2p425

Aguilar, A.G., P.M. Ward, and C.B. Smith (2003). Globalization, regional development, and mega-city expansion in Latin America: Analyzing Mexico City's peri-urban hinterland. *Cities* **20**, 3–21. doi: 10.1016/S0264-2751(02)00092-6, ISSN: 0264-2751.

Aguilera A. (2008). Business travel and mobile workers. *Transportation Research Part A: Policy and Practice* **42**, 1109–1116. doi: 10.1016/j.tra.2008.03.005, ISSN: 0965-8564.

Agyeman K.O., O. Amponsah, I. Braimah, and S. Lurumuah (2012). Commercial Charcoal Production and Sustainable Community Development of the Upper West Region, Ghana. *Journal of Sustainable Development* **5**, 149–164. doi: 10.5539/jsd.v5n4p149, ISSN: 1913-9071.

Akbari, H. and H.D. Matthews (2012). Global cooling updates: Reflective roofs and pavements. Energy and Buildings 55, 2–6. doi: 10.1016/j.enbuild.2012.02.055

Akbari H., S. Menon, and A. Rosenfeld (2008). Global cooling: increasing world-wide urban albedos to offset CO_2. *Climatic Change* **94**, 275–286. doi: 10.1007/s10584-008-9515-9.

Akbari H., M. Pomerantz, and H. Taha (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy* **70**, 295–310. doi: 10.1016/S0038-092X(00)00089-X, ISSN: 0038-092X.

Alkema L., A.E. Raftery, P. Gerland, S.J. Clark, F. Pelletier, T. Buettner, and G.K. Heilig (2011). Probabilistic Projections of the Total Fertility Rate for All Countries. *Demography* **48**, 815–839. doi: 10.1007/s13524-011-0040-5, ISSN: 0070-3370, 1533–7790.

Allwood J.M., J.M. Cullen, and R.L. Milford (2010). Options for Achieving a 50% Cut in Industrial Carbon Emissions by 2050. *Environmental Science & Technology* **44**, 1888–1894. doi: 10.1021/es902909k, ISSN: 0013-936X.

Alterman R. (1997). The Challenge of Farmland Preservation: Lessons from a Six-Nation Comparison. *Journal of the American Planning Association* **63**, 220–243. doi: 10.1080/01944369708975916, ISSN: 0194-4363, 1939–0130.

Altes W.K.K. (2009). Taxing land for urban containment: Reflections on a Dutch debate. *Land Use Policy* **26**, 233–241. doi: 10.1016/j.landusepol.2008.01.006, ISSN: 02648377.

Amati M. (2008). Green belts: a twentieth-century planning experiment. In: *Urban green belts in the twenty-first century*. M. Amati, (ed.), Ashgate, pp. 1–17. ISBN: 978-0-7546-4959-5.

Andreev P., I. Salomon, and N. Pliskin (2010). Review: State of teleactivities. *Transportation Research Part C: Emerging Technologies* **18**, 3–20. doi: 10.1016/j.trc.2009.04.017, ISSN: 0968-090X.

Angel S., J. Parent, D.L. Civco, and A.M. Blei (2010). The persistent decline in urban densities: Global and historical evidence of sprawl. *Lincoln Institute of Land Policy Working Paper*. Available at: http://urb.iiedlist.org/sites/default/files/Angel%202010-declineinurbandensities.pdf.

Angel S., J. Parent, D.L. Civco, A. Blei, and D. Potere (2011). The dimensions of global urban expansion: Estimates and projections for all countries, 2000–2050. *Progress in Planning* **75**, 53–107. doi: 10.1016/j.progress.2011.04.001, ISSN: 0305-9006.

Angel S., S.C. Sheppard, D.L. Civco, R. Buckley, A. Chabaeva, L. Gitlin, A. Kraley, J. Parent, and M. Perlin (2005). *The Dynamics of Global Urban Expansion*. Transport and Urban Development Department, World Bank, Washington, D.C., 207 pp. Available at: http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/dynamics_urban_expansion.pdf.

Arbesman S., J.M. Kleinberg, and S.H. Strogatz (2009). Superlinear scaling for innovation in cities. *Physical Review E* **79**, 016115. doi: 10.1103/PhysRevE.79.016115.

Arikan Y. (2011). *Carbonn Cities Climate Registry 2011 Annual Report*. Bonn Center for Local Climate Action and Reporting, Bonn. Available at: http://citiesclimateregistry.org/resources/newsletters-and-reports/.

Arrington G.B., and R. Cervero (2008). *Effects of TOD on Housing, Parking, and Travel*. Transit Cooperative Research Program, Washington, D.C., ISBN: 9780309117487, 0309117488. Available at: http://www.reconnectingamerica.org/assets/Uploads/finalreporttcrp128.pdf.

Arthur W.B. (1989). Competing Technologies, Increasing Returns, and Lock-In by Historical Events. *The Economic Journal* **99**, 116–131. doi: 10.2307/2234208, ISSN: 0013-0133.

ARUP (2011). *Climate Action in Megacities: C40 Cities Baseline and Opportunities*. C40 Cities, Available at: http://www.arup.com/Publications/Climate_Action_in_Megacities.aspx.

Aumnad P. (2010). Integrated energy and carbon modeling with a decision support system: Policy scenarios for low-carbon city development in Bangkok. *Energy Policy* **38**, 4808–4817. doi: 10.1016/j.enpol.2009.10.026, ISSN: 0301-4215.

Aurand A. (2010). Density, Housing Types and Mixed Land Use: Smart Tools for Affordable Housing? *Urban Studies* **47**, 1015–1036. doi: 10.1177/0042098009353076, ISSN: 0042-0980.

Ausubel J.H., and R. Herman (1988). *Cities and Their Vital Systems: Infrastructure Past, Present, and Future*. National Academies Press, Washington, D.C., 368 pp. ISBN: 0309555167.

Axhausen K. (2008). Accessibility Long Term Perspectives. *Journal of Transport and Land Use* **1**, 5–22. doi: 10.5198/jtlu.v1i2.66, ISSN: 1938-7849.

Azar C., K. Lindgren, M. Obersteiner, K. Riahi, D.P. van Vuuren, K.M.G.J. den Elzen, K. Möllersten, and E.D. Larson (2010). The feasibility of low CO_2 concentration targets and the role of bio-energy with carbon capture and storage (BECCS). *Climatic Change* **100**, 195–202. doi: 10.1007/s10584-010-9832-7, ISSN: 0165-0009, 1573–1480.

Bader N., and R. Bleischwitz (2009). Measuring Urban Greenhouse Gas Emissions: The Challenge of Comparability. *S.A.P.I.EN.S* **2**, 1–15. ISSN: 1993-3800.

Bae C.-H.C., and M.-J. Jun (2003). Counterfactual Planning What if there had been No Greenbelt in Seoul? *Journal of Planning Education and Research* **22**, 374–383. doi: 10.1177/0739456X03022004004, ISSN: 0739-456X, 1552–6577.

Bahl R.W., and J.F. Linn (1998). *Urban Public Finance in Developing Countries*. Oxford University Press, New York, ISBN: 9780195211221.

Bailis R., M. Ezzati, and D.M. Kammen (2005). Mortality and Greenhouse Gas Impacts of Biomass and Petroleum Energy Futures in Africa. *Science* **308**, 98–103. doi: 10.1126/science.1106881, ISSN: 0036-8075, 1095–9203.

Bangkok Metropolitan Administration (2013). *Bangkok, The Green City*.

Banister D. (2005). *Unsustainable Transport: City Transport in the New Century*. Routledge, Oxfordshire, England, 292 pp. ISBN: 978415357829.

Banister D. (2008). The sustainable mobility paradigm. *Transport Policy* **15**, 73–80. doi: 10.1016/j.tranpol.2007.10.005, ISSN: 0967-070X.

Banister D. (2011). Cities, mobility and climate change. *Journal of Transport Geography* **19**, 1538–1546. doi: 10.1016/j.jtrangeo.2011.03.009, ISSN: 0966-6923.

Banzhaf H.S., and N. Lavery (2010). Can the land tax help curb urban sprawl? Evidence from growth patterns in Pennsylvania. *Journal of Urban Economics* **67**, 169–179. doi: 10.1016/j.jue.2009.08.005, ISSN: 00941190.

Barbour E., and E.A. Deakin (2012). Smart Growth Planning for Climate Protection. *Journal of the American Planning Association* **78**, 70–86. doi: 10.1080/01944363.2011.645272, ISSN: 0194-4363.

Barter P.A. (2011). Parking Requirements in Some Major Asian Cities. *Transportation Research Record: Journal of the Transportation Research Board* **2245**, 79–86. doi: 10.3141/2245-10, ISSN: 0361-1981.

Bassett E., and V. Shandas (2010). Innovation and Climate Action Planning: Perspectives from Muncipal Plans. *Journal of the American Planning Association* **76**, 435–450. doi: 10.1080/01944363.2010.509703, ISSN: 0194-4363.

Batt H.W. (2001). Value Capture as a Policy Tool in Transportation Economics: An Exploration in Public Finance in the Tradition of Henry George. *American Journal of Economics and Sociology* **60**, 195–228. doi:10.1111/1536-7150.00061.

Batty M. (2007). *Cities and Complexity: Understanding Cities Through Cellular Automata, Agent-Based Models and Fractals*. The MIT Press, Cambridge, MA, 565 pp. ISBN: 0262025833.

Batty M. (2008). The Size, Scale, and Shape of Cities. *Science* **319**, 769–771. doi: 10.1126/science.1151419, ISSN: 0036-8075, 1095–9203.

Bauman G., and W.H. Ethier (1987). Development Exactions and Impact Fees: A Survey of American Practices. *Land Use Law & Zoning Digest* **39**, 3–11. doi: 10.1080/00947598.1987.10395091, ISSN: 0094-7598.

Baum-Snow N. (2007). Did Highways Cause Suburbanization? *The Quarterly Journal of Economics* **122**, 775–805. doi: 10.1162/qjec.122.2.775, ISSN: 0033-5533, 1531–4650.

Baynes T., M. Lenzen, J.K. Steinberger, and X. Bai (2011). Comparison of household consumption and regional production approaches to assess urban energy use and implications for policy. *Energy Policy* **39**, 7298–7309. ISSN: 0301-4215. doi: 10.1016/j.enpol.2011.08.053.

Beatley T. (2000). *Green Urbanism: Learning From European Cities*. Island Press, Washington, D.C., 514 pp. ISBN: 9781610910132.

Beauregard R.A., and A. Marpillero-Colomina (2011). More than a master plan: Amman 2025. *Cities* **28**, 62–69. doi: 10.1016/j.cities.2010.09.002, ISSN: 0264-2751.

Bedsworth L.W., and E. Hanak (2013). Climate policy at the local level: Insights from California. *Global Environmental Change* **23**, 664–677. doi: 10.1016/j.gloenvcha.2013.02.004, ISSN: 09593780.

Beevers S., and D. Carslaw (2005). The impact of congestion charging on vehicle emissions in London. *Atmospheric Environment* **39**, 1–5. doi: 10.1016/j.atmosenv.2004.10.001, ISSN: 13522310.

Benediktsson J.A., M. Pesaresi, and K. Amason (2003). Classification and feature extraction for remote sensing images from urban areas based on morphological transformations. *IEEE Transactions on Geoscience and Remote Sensing* **41**, 1940–1949. doi: 10.1109/TGRS.2003.814625, ISSN: 0196-2892.

Bengston D.N., J.O. Fletcher, and K.C. Nelson (2004). Public policies for managing urban growth and protecting open space: policy instruments and lessons learned in the United States. *Landscape and Urban Planning* **69**, 271–286. doi: 10.1016/j.landurbplan.2003.08.007, ISSN: 0169-2046.

Bengston D.N., and Y.-C. Youn (2006). Urban containment policies and the protection of natural areas: the case of Seoul's greenbelt. *Ecology and Society* **11**, 1–15. Available at: http://www.ecologyandsociety.org/vol11/iss1/art3/.

Benjamin J.D., and G.S. Sirmans (1996). Mass Transportation, Apartment Rent and Property Values. *Journal of Real Estate Research* **12**, 1–8. Available at: http://ares.metapress.com/content/3t94up166n288076/.

Bento A.M., M.L. Cropper, A.M. Mobarak, and K. Vinha (2005). The Effects of Urban Spatial Structure on Travel Demand in the United States. *Review of Economics and Statistics* **87**, 466–478. doi: 10.1162/0034653054638292, ISSN: 0034-6535.

Bento A.M., S.F. Franco, and D. Kaffine (2006). The Efficiency and Distributional Impacts of Alternative Anti-sprawl Policies. *Journal of Urban Economics* **59**, 121–141. doi: 10.1016/j.jue.2005.09.004, ISSN: 00941190.

Bento A.M., S.F. Franco, and D. Kaffine (2011). Is there a double-dividend from anti-sprawl policies? *Journal of Environmental Economics and Management* **61**, 135–152. doi: 10.1016/j.jeem.2010.09.002, ISSN: 00950696.

Berke E.M., L.M. Gottlieb, A.V. Moudon, and E.B. Larson (2007). Protective Association Between Neighborhood Walkability and Depression in Older Men. *Journal of the American Geriatrics Society* **55**, 526–533. doi: 10.1111/j.1532-5415.2007.01108.x, ISSN: 1532-5415.

Berndes G., M. Hoogwijk, and R. van den Broek (2003). The contribution of biomass in the future global energy supply: a review of 17 studies. *Biomass and Bioenergy* **25**, 1–28. doi: 10.1016/S0961-9534(02)00185-X, ISSN: 0961-9534.

Bernick M., and R. Cervero (1996). *Transit Villages in the 21st Century*. McGraw-Hill, New York, 387 pp. ISBN: 978-0070054752.

Bernt M. (2009). Partnerships for Demolition: The Governance of Urban Renewal in East Germany's Shrinking Cities. *International Journal of Urban and Regional Research* **33**, 754–769. doi: 10.1111/j.1468-2427.2009.00856.x, ISSN: 1468-2427.

Berry B.J.L. (1973). *The Human Consequences of Urbanisation: Divergent Paths in the Urban Experience of the Twentieth Century*. Macmillan, London, 205 pp. ISBN: 9780312398651.

Berry B.J.L., and W.L. Garrison (1958). Alternate Explanations of Urban Rank–Size Relationships. *Annals of the Association of American Geographers* **48**, 83–90. doi: 10.1111/j.1467-8306.1958.tb01559.x, ISSN: 0004-5608.

Berry B.J.L., F.E. Horton, and J.O. Abiodun (1970). *Geographic Perspectives on Urban Systems with Integrated Readings*. Prentice-Hall, Englewood Cliffs, N.J., 564 pp. ISBN: 9780133513127.

Bertaud A., and S. Malpezzi (2003). *The Spatial Distribution of Population in 48 World Cities: Implications for Economies in Transition*. University of Wisconsin, Madison, 102 pp. Available at: http://alain-bertaud.com/AB_Files/Spatia_%20Distribution_of_Pop_%2050_%20Cities.pdf.

Betsill M.M. (2001). Mitigating Climate Change in US Cities: Opportunities and obstacles. *Local Environment* **6**, 393–406. doi: 10.1080/13549830120091699, ISSN: 1354-9839.

Bettencourt L.M.A., J. Lobo, D. Helbing, C. Kühnert, and G.B. West (2007). Growth, innovation, scaling, and the pace of life in cities. *Proceedings of the National Academy of Sciences* **104**, 7301–7306. doi: 10.1073/pnas.0610172104, ISSN: 0027-8424, 1091–6490.

Bettencourt L.M.A., J. Lobo, D. Strumsky, and G.B. West (2010). Urban Scaling and Its Deviations: Revealing the Structure of Wealth, Innovation and Crime across Cities. *PLoS ONE* **5**, e13541. doi: 10.1371/journal.pone.0013541.

Bhatia R. (2004). Land use: A key to livable transportation. In: *The Square in North America*. International Making Cities Livable Council, London. Available at: http://www.livablecities.org/conferences/40th-conference-london/program.

Bhatt K. (2011). Congestion Pricing: An Overview of Experience and Impacts. In: *Climate Change and Land Policies*. G.K. Ingram, Y.-H. Hong, (eds.), Lincoln Institute of Land Policy, Cambridge, MA, pp. 247–271.

Bird R.M., and E. Slack (2002). Land and property taxation around the world: a review. *Journal of Property Tax Assessment and Administration* **7**, 31–80.

Bird R.M., and E. Slack (2007). Taxing Land and Property in Emerging Economies: Raising Revenue . . . and More? In: *Land Policies and Their Outcomes*. G.K. Ingram, Y.-H. Hong, (eds.), Lincoln Institute of Land Policy, Cambridge, MA, pp. 204–233.

Blackman I.Q., and D.H. Picken (2010). Height and Construction Costs of Residential High-Rise Buildings in Shanghai. *Journal of Construction Engineering and Management* **136**, 1169–1180. ISSN: 0733-9364. doi: 10.1061/(ASCE)CO.1943-7862.0000226.

Blanco H., P.L. McCarney, S. Parnell, M. Schmidt, and K.C. Seto (2011). The Role of Urban Land in Climate Change. In: *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*. C. Rosenzweig, W.D. Solecki, S.A. Hammer, S. Mehrotra, (eds.), Cambridge University Press, Cambridge, UK, pp. 217–248. ISBN: 9781107004207.

Boarnet M.G., and R. Crane (2001). *Travel by Design: The Influence of Urban Form on Travel*. Oxford University Press, New York, NY, 238 pp. ISBN: 9780195352467.

Boarnet M.G., K.S. Nesamani, and C.S. Smith (2003). Comparing the influence of land use on nonwork trip generation and vehicle distance travelled: An analysis using travel diary data. In: *Paper presented at the 83rd annual meeting of the Transportation Research Board, Washington, DC.* Available at: https://escholarship.org/uc/item/4xf6r519

Bocquier P. (2005). World Urbanization Prospects: an alternative to the UN model of projection compatible with the mobility transition theory. *Demographic Research* **12**, 197–236. doi: 10.4054/DemRes.2005.12.9, ISSN: 1435-9871.

Bongaarts J. (2001). Household Size and Composition in the Developing World in the 1990s. *Population Studies* **55**, 263–279. doi: 10.1080/00324720127697, ISSN: 0032-4728.

Bontje M. (2005). Facing the challenge of shrinking cities in East Germany: The case of Leipzig. *GeoJournal* **61**, 13–21. doi: 10.1007/s10708-005-0843-2, ISSN: 0343-2521, 1572–9893.

Boswell M.R., A.I. Greve, and T.L. Seale (2010). An Assessment of the Link Between Greenhouse Gas Emissions Inventories and Climate Action Plans. *Journal of the American Planning Association* **76**, 451–462. doi: 10.1080/01944363.2010.503313, ISSN: 0194-4363.

Boswell M.R., A.I. Greve, and T.L. Seale (2011). *Local Climate Action Planning*. Island Press, Washington, DC. 304pp, ISBN: 9781597269629.

Bourdic L., S. Salat, and C. Nowacki (2012). Assessing cities: a new system of cross-scale spatial indicators. *Building Research & Information* **40**, 592–605. doi: 10.1080/09613218.2012.703488, ISSN: 0961-3218.

Boyko C.T., and R. Cooper (2011). Clarifying and re-conceptualising density. *Progress in Planning* **76**, 1–61. doi: 10.1016/j.progress.2011.07.001, ISSN: 0305-9006.

Boyle R., and R. Mohamed (2007). State growth management, smart growth and urban containment: A review of the US and a study of the heartland. *Journal of Environmental Planning and Management* **50**, 677–697. doi: 10.1080/09640560701475337, ISSN: 0964-0568, 1360–0559.

Brambilla R., and G. Longo (1977). *For Pedestrians Only: Planning, Design and Management of Traffic-Free Zones*. Whitney Library of Design, New York, 208 pp.

Bräutigam D.A., and S. Knack (2004). Foreign Aid, Institutions, and Governance in Sub-Saharan Africa. *Economic Development and Cultural Change* **52**, 255–285. doi: 10.1086/380592, ISSN: 0013-0079.

Brown J.H., J.F. Gillooly, A.P. Allen, V.M. Savage, and G.B. West (2004). Toward a Metabolic Theory of Ecology. *Ecology* **85**, 1771–1789. doi: 10.1890/03-9000, ISSN: 0012-9658.

Brown L.A., and J. Holmes (1971). The Delimitation of Functional Regions, Nodal Regions, and Hierarchies by Functional Distance Approaches. *Journal of Regional Science* **11**, 57–72. doi: 10.1111/j.1467-9787.1971.tb00240.x, ISSN: 1467-9787.

Brownstone D., and T.F. Golob (2009). The impact of residential density on vehicle usage and energy consumption. *Journal of Urban Economics* **65**, 91–98. doi: 10.1016/j.jue.2008.09.002.

Brownsword R.A., P.D. Fleming, J.C. Powell, and N. Pearsall (2005). Sustainable cities—modelling urban energy supply and demand. *Applied Energy* **82**, 167–180. doi: 10.1016/j.apenergy.2004.10.005, ISSN: 03062619.

Brueckner J.K. (2000). Urban Sprawl: Diagnosis and Remedies. *International Regional Science Review* **23**, 160–171. doi: 10.1177/016001700761012710, ISSN: 0160-0176, 1552–6925.

Brueckner J.K. (2001a). Urban Sprawl: Lessons from Urban Economics. *Brookings-Wharton Papers on Urban Affairs* **2001**, 65–97. doi: 10.1353/urb.2001.0003, ISSN: 1533-4449.

Brueckner J.K. (2001b). Tax increment financing: a theoretical inquiry. *Journal of Public Economics* **81**, 321–343. doi: 10.1016/S0047-2727(00)00123-7, ISSN: 0047-2727.

Brueckner J.K. (2005). Transport subsidies, system choice, and urban sprawl. *Regional Science and Urban Economics* **35**, 715–733. doi: 10.1016/j.regsciurbeco.2005.01.001, ISSN: 0166-0462.

Brueckner J.K., and D.A. Fansler (1983). The Economics of Urban Sprawl: Theory and Evidence on the Spatial Sizes of Cities. *The Review of Economics and Statistics* **65**, 479–482. doi: 10.2307/1924193, ISSN: 0034-6535.

Brueckner J.K., and R.W. Helsley (2011). Sprawl and blight. *Journal of Urban Economics* **69**, 205–213. doi: 10.1016/j.jue.2010.09.003, ISSN: 0094-1190.

Brueckner J.K., and H.-A. Kim (2003). Urban Sprawl and the Property Tax. *International Tax and Public Finance* **10**, 5–23. Kluwer Academic Publishers, doi: 10.1023/A:1022260512147, ISSN: 1573-6970.

Brueckner J.K., and K.S. Sridhar (2012). Measuring welfare gains from relaxation of land-use restrictions: The case of India's building-height limits. *Regional Science and Urban Economics* **42**, 1061–1067. doi: 10.1016/j.regsciurbeco.2012.08.003, ISSN: 0166-0462.

Brueckner J.K., J.-F. Thisse, and Y. Zenou (1999). Why is central Paris rich and downtown Detroit poor?: An amenity-based theory. *European Economic Review* **43**, 91–107. doi: 10.1016/S0014-2921(98)00019-1, ISSN: 0014-2921.

Buisseret D. (Ed.) **(1998).** *Envisioning the City: Six Studies in Urban Cartography*. University of Chicago Press, Chicago, IL, 196 pp. ISBN: 978-0226079936.

Bulkeley H. (2013). *Cities and Climate Change*. Routledge, New York, NY, 344 pp. ISBN: 9781135130114.

Bulkeley H., and M.M. Betsill (2005). *Cities and Climate Change: Urban Sustainability and Global Environmental Governance*. Psychology Press, 250 pp. ISBN: 9780415273794.

Bulkeley H., and K. Kern (2006). Local government and the governing of climate change in Germany and the UK. *Urban Studies* **43**, 2237–2259. doi: 10.1080/00420980600936491, ISSN: 00420980.

Bulkeley H., and H. Schroeder (2012). Beyond state/non-state divides: Global cities and the governing of climate change. *European Journal of International Relations* **18**, 743–766. doi: 10.1177/1354066111413308, ISSN: 13540661.

Bunting T., P. Filion, and H. Priston (2002). Density Gradients in Canadian Metropolitan Regions, 1971–96: Differential Patterns of Central Area and Suburban Growth and Change. *Urban Studies* **39**, 2531–2552. doi: 10.1080/0042098022000027095.

Burchell R., A. Downs, B. McCann, and S. Mukherji (2005). *Sprawl Costs: Economic Impacts of Unchecked Development*. Island Press, Washington, D.C., 209 pp. ISBN: 9781597262507.

Burchfield M., H.G. Overman, D. Puga, and M.A. Turner (2006). Causes of Sprawl: A Portrait from Space. *The Quarterly Journal of Economics* **121**, 587–633. doi: 10.1162/qjec.2006.121.2.587, ISSN: 0033-5533, 1531–4650.

Button K. (2010). *Transport Economics*. Edward Elgar, Cheltenham, 528 pp. ISBN: 978-1840641912.

C40 Cities (2013). *C40 Cities Climate Leadership Group*. Available at: http://www.c40cities.org/c40cities.

Callies D.L. (1979). A Hypothetical Case: Value Capture/Joint Development Techniques to Reduce the Public Costs of Public Improvements. *Urban Law Annual* **16**, 155–192. Available at: http://heinonline.org/HOL/LandingPage?handle=hein.journals/waucl16&div=5.

Calthorpe P. (2013). *Urbanism in the Age of Climate Change*. Island Press, Washington, D.C., 176 pp. ISBN: 9781597267212.

Calthorpe P., and W. Fulton (2001). *The Regional City: Planning for the End of Sprawl*. Island Press, Washington, D.C., 298 pp. ISBN: 9781597266215.

Campbell-Lendrum D., and C. Corvalán (2007). Climate Change and Developing-Country Cities: Implications For Environmental Health and Equity. *Journal of Urban Health: Bulletin of the New York Academy of Medicine* **84**, 109–117. doi: 10.1007/s11524-007-9170-x, ISSN: 1099-3460.

Carbon Disclosure Project (2013). *CDP Cities 2013: Summary Report on 110 Global Cities*. Carbon Disclosure Project, London, 35 pp. Available at: http://www.cdpcities2013.net/doc/CDP-Summary-Report.pdf.

Carlino G.A., S. Chatterjee, and R.M. Hunt (2007). Urban density and the rate of invention. *Journal of Urban Economics* **61**, 389–419. doi: 10.1016/j.jue.2006.08.003, ISSN: 00941190.

Carney S., N. Green, R. Wood, and R. Read (2009). *Greenhouse Gas Emissions Inventories for 18 European Regions: EU CO_2 80/50 Project Stage 1: Inventory Formation. The Greenhouse Gas Regional Inventory Protocol (GRIP)*. Centre for Urban and Regional Ecology, School of Environment and Development, The University of Manchester, Manchester.

Carvalho R., and A. Penn (2004). Scaling and universality in the micro-structure of urban space. *Physica A: Statistical Mechanics and Its Applications* **332**, 539–547. doi: 10.1016/j.physa.2003.10.024, ISSN: 0378-4371.

Castán Broto V., and H. Bulkeley (2012). A survey of urban climate change experiments in 100 cities. *Global Environmental Change* **23**, 92–102. doi: 10.1016/j.gloenvcha.2012.07.005, ISSN: 0959-3780.

Cervero R. (1989). Jobs-Housing Balancing and Regional Mobility. *Journal of the American Planning Association* **55**, 136–150. doi: 10.1080/01944368908976014, ISSN: 0194-4363.

Cervero R. (1995a). Sustainable new towns: Stockholm's rail-served satellites. *Cities* **12**, 41–51. doi: 10.1016/0264-2751(95)91864-C, ISSN: 0264-2751.

Cervero R. (1995b). Planned Communities, Self-containment and Commuting: A Cross-national Perspective. *Urban Studies* **32**, 1135–1161. doi: 10.1080/00420989550012618, ISSN: 0042-0980, 1360–063X.

Cervero R. (1996). Mixed land-uses and commuting: Evidence from the American Housing Survey. *Transportation Research Part A: Policy and Practice* **30**, 361–377. doi: 10.1016/0965-8564(95)00033-X, ISSN: 09658564.

Cervero R. (1998). *The Transit Metropolis: A Global Inquiry*. Island Press, Washington, D.C., 480 pp. ISBN: 1559635916, 9781559635912.

Cervero R. (2006). Public Transport and Sustainable Urbanism: Global Lessons. *University of California Transportation Center*, 1–10. http://escholarship.org/uc/item/4fp6x44f.

Cervero R. (2013). Linking urban transport and land use in developing countries. *Journal of Transport and Land Use* **6**, 7–24. doi: 10.5198/jtlu.v6i1.425, ISSN: 1938-7849.

Cervero R., and J. Day (2008). Suburbanization and transit-oriented development in China. *Transport Policy* **15**, 315–323. doi: 10.1016/j.tranpol.2008.12.011, ISSN: 0967-070X.

Cervero R., and M. Duncan (2006). Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing? *Journal of the American Planning Association* **72**, 475–490. doi: 10.1080/01944360608976767, ISSN: 0194-4363.

Cervero R., and M. Hansen (2002). Induced travel demand and induced road investment: a simultaneous equation analysis. *Journal of Transport Economics and Policy* **36**, 469–490. Available at: http://www.jstor.org/stable/10.2307/20053915.

Cervero R., and K. Kockelman (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment* **2**, 199–219. doi: 10.1016/S1361-9209(97)00009-6, ISSN: 1361-9209.

Cervero R., S. Murphy, C. Ferrell, N. Goguts, Y.-H. Tsai, G.B. Arrington, J. Boroski, J. Smith-Heimer, R. Golem, P. Peninger, E. Nakajima, E. Chui, R. Dunphy, M. Myers, S. McKay, and N. Witenstein (2004). *Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects*. Transportation Research Board, Washington, D.C., 481 pp. http://www.worldtransitresearch.info/research/3066/.

Cervero R., O.L. Sarmiento, E. Jacoby, L.F. Gomez, and A. Neiman (2009). Influences of Built Environments on Walking and Cycling: Lessons from Bogotá. *International Journal of Sustainable Transportation* **3**, 203–226. doi: 10.1080/15568310802178314, ISSN: 1556-8318.

Cervero R., and C. Sullivan (2011). Green TODs: marrying transit-oriented development and green urbanism. *International Journal of Sustainable Development & World Ecology* **18**, 210–218. doi: 10.1080/13504509.2011.570801, ISSN: 1350-4509, 1745–2627.

Chandler T. (1987). *Four Thousand Years of Urban Growth: An Historical Census*. St. David's University Press, Lewiston, NY, 656 pp. ISBN: 9780889462076.

Chapman J., and L. Frank (2007). *Integrating Travel Behavior and Urban Form Data to Address Transportation and Air Quality Problems in Atlanta*. Georgia Institute of Technology, Atlanta, 302 pp. Available at: http://atl.sites.olt.ubc.ca/files/2011/06/GDOT_final_report.pdf.

Chavez A., and A. Ramaswami (2011). Progress toward low carbon cities: approaches for transboundary GHG emissions' footprinting. *Carbon Management* **2**, 471–482. doi: 10.4155/cmt.11.38, ISSN: 1758-3004.

Chavez A., and A. Ramaswami (2013). Articulating a trans-boundary infrastructure supply chain greenhouse gas emission footprint for cities: Mathematical relationships and policy relevance. *Energy Policy* **54**, 376–384. doi: 10.1016/j.enpol.2012.10.037, ISSN: 0301-4215.

Chavez A., A. Ramaswami, D. Nath, R. Guru, and E. Kumar (2012). Implementing Trans-Boundary Infrastructure-Based Greenhouse Gas Accounting for Delhi, India. *Journal of Industrial Ecology* **16**, 814–828. doi: 10.1111/j.1530-9290.2012.00546.x, ISSN: 1530-9290.

Chen H., B. Jia, and S.S.Y. Lau (2008). Sustainable urban form for Chinese compact cities: Challenges of a rapid urbanized economy. *Habitat International* **32**, 28–40. doi: 10.1016/j.habitatint.2007.06.005, ISSN: 0197-3975.

Chen N., P. Valente, and H. Zlotnik (1998). What do we know about recent trends in urbanization? In: *Migration, Urbanization, and Development: New Directions and Issues*. R.E. Bilsborrow, (ed.), UNFPA-Kluwer Academic Publishers, Norwell, MA, pp. 59–88.

Cheng V. (2009). Understanding density and high density. In: *Designing High-Density Cities for Social and Environmental Sustainability.*. Earthscan, London; Sterling, VA, pp. 3–17. ISBN: 9781844074600.

Cherp A., A. Adenikinju, A. Goldthau, F. Hernandez, L. Hughes, J. Jansen, J. Jewell, M. Olshanskaya, R. Soares de Oliveira, B. Sovacool, and S. Vakulenko (2012). Energy and Security. In: *Global Energy Assessment: Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 325–383. Available at: http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter5_security_lowres.pdf.

Chertow M.R. (2000). The IPAT Equation and Its Variants. *Journal of Industrial Ecology* **4**, 13–29. doi: 10.1162/10881980052541927, ISSN: 1530-9290.

Chong W.H.B., D. Guan, and P. Guthrie (2012). Comparative Analysis of Carbonization Drivers in China's Megacities. *Journal of Industrial Ecology* **16**, 564–575. doi: 10.1111/j.1530-9290.2012.00519.x, ISSN: 10881980.

Choo S., P.L. Mokhtarian, and I. Salomon (2005). Does telecommuting reduce vehicle-miles traveled? An aggregate time series analysis for the U.S. *Transportation* **32**, 37–64. doi: 10.1007/s11116-004-3046-7, ISSN: 0049-4488, 1572–9435.

Chorus P. (2009). Transit Oriented Development in Tokyo: The Public Sector Shapes Favourable Conditions, the Private Sector Makes it Happen. In: *Transit Oriented Development: Making it Happen*. C. Curtis, J.L. Renne, L. Bertolini, (eds.), Ashgate, Surrey, England, pp. 225–238. ISBN: 9780754673156.

Chowdhury Z., M. Zheng, J.J. Schauer, R.J. Sheesley, L.G. Salmon, G.R. Cass, and A.G. Russell (2007). Speciation of ambient fine organic carbon particles and source apportionment of $PM_{2.5}$ in Indian cities. *Journal of Geophysical Research* **112**, 1–14. doi: 10.1029/2007JD008386, ISSN: 0148-0227.

Zegras P.C. (2007). As if Kyoto mattered: The clean development mechanism and transportation. *Energy Policy* **35**, 5136–5150. doi: 10.1016/j.enpol.2007.04.032, ISSN: 0301-4215.

Chun M., J. Mei-ting, Z. Xiao-chun, and L. Hong-yuan (2011). Energy consumption and carbon emissions in a coastal city in China. *Procedia Environmental Sciences* **4**, 1–9. doi: 10.1016/j.proenv.2011.03.001, ISSN: 1878-0296.

Churchill R.R. (2004). Urban Cartography and the Mapping of Chicago. *Geographical Review* **94**, 1–22. doi: 10.1111/j.1931-0846.2004.tb00155.x, ISSN: 1931-0846.

Ciccone A., and R.E. Hall (1996). Productivity and the Density of Economic Activity. *American Economic Review* **86**, 54–70. Available at: http://ideas.repec.org/a/aea/aecrev/v86y1996i1p54–70.html.

City of Stockholm (2013). A sustainable city. Available at: http://international.stockholm.se/Politics-and-organisation/A-sustainable-city/.

Clark T.A. (2013). Metropolitan density, energy efficiency and carbon emissions: Multi-attribute tradeoffs and their policy implications. *Energy Policy* **53**, 413–428. doi: 10.1016/j.enpol.2012.11.006, ISSN: 0301-4215.

Cohen C., M. Lenzen, and R. Schaeffer (2005). Energy requirements of households in Brazil. *Energy Policy* **33**, 555–562. doi: 10.1016/j.enpol.2003.08.021, ISSN: 0301-4215.

Cole R.J. (1998). Energy and greenhouse gas emissions associated with the construction of alternative structural systems. *Building and Environment* **34**, 335–348. doi: 10.1016/S0360-1323(98)00020-1, ISSN: 0360-1323.

Colette A., C. Granier, Ø. Hodnebrog, H. Jakobs, A. Maurizi, A. Nyiri, S. Rao, M. Amann, B. Bessagnet, A. D'Angiola, M. Gauss, C. Heyes, Z. Klimont, F. Meleux, M. Memmesheimer, A. Mieville, L. Rouïl, F. Russo, S. Schucht, D. Simpson, F. Stordal, F. Tampieri, and M. Vrac (2012). Future air quality in Europe: a multi-model assessment of projected exposure to ozone. *Atmos. Chem. Phys.* **12**, 10613–10630. doi: 10.5194/acp-12-10613-2012, ISSN: 1680-7324.

Covenant of Mayors (2010). *How to Develop a Sustainable Energy Action Plan (SEAP)—Guidebook*. Publications Office of the European Union, Luxembourg, Available at: http://www.eumayors.eu/IMG/pdf/seap_guidelines_en.pdf.

Crassous R., J.-C. Hourcade, and O. Sassi (2006). Endogenous Structural Change and Climate Targets Modeling Experiments with Imaclim-R. *The Energy Journal* **27**, 259–276. doi: 10.2307/23297067, ISSN: 01956574.

Creutzig F., and D. He (2009). Climate change mitigation and co-benefits of feasible transport demand policies in Beijing. *Transportation Research Part D: Transport and Environment* **14**, 120–131. doi: 10.1016/j.trd.2008.11.007, ISSN: 1361-9209.

Curtis C. (2012). Delivering the 'D' in transit-oriented development: Examining the town planning challenge. *Journal of Transport and Land Use* **5**, 83–99. doi: 10.5198/jtlu.v5i3.292.

Curtis C., J.L. Renne, and L. Bertolini (Eds.) **(2009).** *Transit Oriented Development: Making It Happen*. Ashgate, Surrey, England, 291 pp. ISBN: 9780754673156.

Cutter W.B., and S.F. Franco (2012). Do parking requirements significantly increase the area dedicated to parking? A test of the effect of parking requirements values in Los Angeles County. *Transportation Research Part A: Policy and Practice* **46**, 901–925. doi: 10.1016/j.tra.2012.02.012.

Dalton M., B. O'Neill, A. Prskawetz, L. Jiang, and J. Pitkin (2008). Population aging and future carbon emissions in the United States. *Energy Economics* **30**, 642–675. doi: 10.1016/j.eneco.2006.07.002.

Daniels T. (1998). *When City and Country Collide: Managing Growth In The Metropolitan Fringe*. Island Press, 361 pp. ISBN: 9781610913478.

Davis K. (1955). The Origin and Growth of Urbanization in the World. *American Journal of Sociology* **60**, 429–437. doi: 10.2307/2772530, ISSN: 0002-9602.

Davis S.J., K. Caldeira, and H.D. Matthews (2010). Future CO_2 Emissions and Climate Change from Existing Energy Infrastructure. *Science* **329**, 1330–1333. doi: 10.1126/science.1188566, ISSN: 0036-8075, 1095–9203.

Davis J.C., and J.V. Henderson (2003). Evidence on the political economy of the urbanization process. *Journal of Urban Economics* **53**, 98–125. doi: 10.1016/S0094-1190(02)00504-1, ISSN: 0094-1190.

Dawkins C.J., and A.C. Nelson (2002). Urban containment policies and housing prices: an international comparison with implications for future research. *Land Use Policy* **19**, 1–12. doi: 10.1016/S0264-8377(01)00038-2.

Day J., and R. Cervero (2010). Effects of Residential Relocation on Household and Commuting Expenditures in Shanghai, China. *International Journal of Urban and Regional Research* **34**, 762–788. doi: 10.1111/j.1468-2427.2010.00916.x, ISSN: 1468-2427.

Debrezion G., E. Pels, and P. Rietveld (2007). The Impact of Railway Stations on Residential and Commercial Property Value: A Meta-analysis. *The Journal of Real Estate Finance and Economics* **35**, 161–180. doi: 10.1007/s11146-007-9032-z, ISSN: 0895-5638, 1573–045X.

Decker E.H., S. Elliott, F.A. Smith, D.R. Blake, and F.S. Rowland (2000). Energy and Material Flow Through the Urban Ecosystem. *Annual Review of Energy and the Environment* **25**, 685–740. doi: 10.1146/annurev.energy.25.1.685.

Decker E.H., A.J. Kerkhoff, and M.E. Moses (2007). Global Patterns of City Size Distributions and Their Fundamental Drivers. *PLoS ONE* **2**, e934. doi: 10.1371/journal.pone.0000934.

DeGrove J.M., and D.A. Miness (1992). *The New Frontier for Land Policy: Planning and Growth Management in the States*. Lincoln Institute of Land Policy, 192 pp. ISBN: 9781558441217.

Delgado-Ramos, G.C. (2013). Climate change and metabolic dynamics in Latin American major cities, in: Zubir, S.S. and Brebbia, C.A. Sustainable City VIII. WIT Press. Southampton, UK. pp. 39–53. ISBN. 978-1-84564-746-9

Deng F.F. (2005). Public land leasing and the changing roles of local government in urban China. *The Annals of Regional Science* **39**, 353–373. doi: 10.1007/s00168-005-0241-1, ISSN: 0570-1864, 1432–0592.

Deng X., J. Huang, S. Rozelle, and E. Uchida (2008). Growth, population and industrialization, and urban land expansion of China. *Journal of Urban Economics* **63**, 96–115. doi: 10.1016/j.jue.2006.12.006, ISSN: 0094-1190.

Department of Energy & Climate Change (2013). *Local Authority CO_2 Emission Estimates 2011*. Department of Energy & Climate Change, London, 38 pp.

DeShazo J.R., and J. Matute (2012). The Local Regulation of Climate Change. In: *The Oxford Handbook of Urban Planning*. R. Crane, R. Weber, (eds.), Oxford University Press, New York, pp. 455–476. ISBN: 9780195374995.

Dewees D.N. (1976). The effect of a subway on residential property values in Toronto. *Journal of Urban Economics* **3**, 357–369. doi: 10.1016/0094-1190(76)90035-8, ISSN: 00941190.

Dhakal S. (2009). Urban energy use and carbon emissions from cities in China and policy implications. *Energy Policy* **37**, 4208–4219. doi: 10.1016/j.enpol.2009.05.020, ISSN: 0301-4215.

Dhakal S. (2010). GHG emissions from urbanization and opportunities for urban carbon mitigation. *Current Opinion in Environmental Sustainability* **2**, 277–283. doi: 10.1016/j.cosust.2010.05.007, ISSN: 1877-3435.

Dhakal S., and L. Poruschi (2010). *Low Carbon City Initiatives: Experiences and lessons from Asia*. Prepared for Consensus Panel on Low Carbon Cities, Academy of Sciences of South Africa.

Dierwechter Y., and A.T. Wessells (2013). The Uneven Localisation of Climate Action in Metropolitan Seattle. *Urban Studies* **50**, 1368–1385. doi: 10.1177/0042098013480969

Dimitriou H.T. (2011). Transport and city development: Understanding the fundamentals. In: *Urban Transport in the Developing World: A Handbook of Policy and Practice*. H.T. Dimitriou, R. Gakenheimer, (eds.), Edward Elgar Publishing, Cheltenham ISBN: 9781849808392.

Doll C.N.H. (2009). *Spatial Analysis of the World Bank's Global Urban Air Pollution Dataset*. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Doll C.N.H., and S. Pachauri (2010). Estimating rural populations without access to electricity in developing countries through night-time light satellite imagery. *Energy Policy* **38**, 5661–5670. doi: 10.1016/j.enpol.2010.05.014, ISSN: 0301-4215.

Doll C.N., M. Dreyfus, S. Ahmad, O. Balaban (2013). Institutional framework for urban development with co-benefits: the Indian experience. *Journal of Cleaner Production* **58**, 121–129. doi: 10.1016/j.jclepro.2013.07.029.

Donglan Z., Z. Dequn, and Z. Peng (2010). Driving forces of residential CO_2 emissions in urban and rural China: An index decomposition analysis. *Energy Policy* **38**, 3377–3383. doi: 10.1016/j.enpol.2010.02.011, ISSN: 03014215.

Dorélien A., D. Balk, and M. Todd (2013). What is Urban? Comparing a satellite view with the demographic and health surveys. *Population and Development Review* **39**, 413–439. doi: 10.1111/j.1728-4457.2013.00610.x, ISSN: 00987921.

Douglass M. (2000). Mega-urban Regions and World City Formation: Globalisation, the Economic Crisis and Urban Policy Issues in Pacific Asia. *Urban Studies* **37**, 2315–2335. doi: 10.1080/00420980020002823, ISSN: 0042-0980, 1360–063X.

Downs A. (2004). *Still Stuck in Traffic: Coping with Peak-Hour Traffic Congestion*. Brookings Institution Press, Washington, D.C., 455 pp. ISBN: 9780815796558.

Droege P. (Ed.) **(2008).** *Urban Energy Transition from Fossil Fuels to Renewable Power*. Elsevier, Amsterdam; Boston; London, 664 pp. ISBN: 9780080453415.

Druckman A., and T. Jackson (2008). Household energy consumption in the UK: A highly geographically and socio-economically disaggregated model. *Energy Policy* **36**, 3177–3192. doi: 10.1016/j.enpol.2008.03.021, ISSN: 0301-4215.

Du H., and C. Mulley (2006). Relationship Between Transport Accessibility and Land Value: Local Model Approach with Geographically Weighted Regression. *Transportation Research Record: Journal of the Transportation Research Board* **1977**, 197–205. doi: 10.3141/1977-25.

Duany A., E. Plater-Zyberk, and J. Speck (2000). *Suburban Nation: The Rise of Sprawl and the Decline of the American Dream*. North Point Press, New York, NY, 324 pp. ISBN: 9780865476066.

Duarte F., and C. Ultramari (2012). Making Public Transport and Housing Match: Accomplishments and Failures of Curitba's BRT. *Journal of Urban Planning and Development* **138**, 183–194. doi: 10.1061/(ASCE)UP.1943-5444.0000107, ISSN: 0733-9488, 1943–5444.

Duncan D.T., G. Piras, E.C. Dunn, R.M. Johnson, S.J. Melly, and B.E. Molnar (2013). The built environment and depressive symptoms among urban youth: A spatial regression study. *Spatial and Spatio-Temporal Epidemiology* **5**, 11–25. doi: 10.1016/j.sste.2013.03.001, ISSN: 1877-5845.

Dupree H. (1987). *Urban Transportation: The New Town Solution*. Gower, Aldershot, U.K., 292 pp. ISBN: 9780566008399.

Dupuy G. (2011). *Towards Sustainable Transport: The Challenge of Car Dependence*. John Libbey Eurotext Limited, Montrouge, France, 66 pp. ISBN: 9782742007936.

Duranton G., and D. Puga (2004). Micro-foundations of urban agglomeration economies. In: *Handbook of Regional and Urban Economics*. J.V. Henderson, J.-F. Thisse, (eds.), Elsevier, pp. 2063–2117. ISBN: 9780444509673.

Duranton G., and M.A. Turner (2011). The Fundamental Law of Road Congestion: Evidence from US Cities. *American Economic Review* **101**, 2616–2652. doi: 10.1257/aer.101.6.2616, ISSN: 0002-8282.

Dye R.F., and D.F. Merriman (2000). The Effects of Tax Increment Financing on Economic Development. *Journal of Urban Economics* **47**, 306–328. doi: 10.1006/juec.1999.2149, ISSN: 0094-1190.

Dye R.F., and J.O. Sundberg (1998). A Model of Tax Increment Financing Adoption Incentives. *Growth and Change* **29**, 90–110. doi: 10.1111/1468-2257.00077, ISSN: 1468-2257.

Edwards M.E. (1984). Site Value Taxation on Australia. *American Journal of Economics and Sociology* **43**, 481–495. doi: 10.1111/j.1536-7150.1984.tb01876.x, ISSN: 0002-9246.

Ekholm T., V. Krey, S. Pachauri, and K. Riahi (2010). Determinants of household energy consumption in India. *Energy Policy* **38**, 5696–5707. doi: 10.1016/j.enpol.2010.05.017, ISSN: 03014215.

Elliot J. (1987). *The City in Maps: Urban Mapping to 1900*. British Library, London, 92 pp. ISBN: 9780712301343.

Elson M.J. (1986). *Green Belts: Conflict Mediation in the Urban Fringe*. Heinemann, Portsmouth, NH, 344 pp. ISBN: 9780434905324.

Enoch M., S. Potter, and S. Ison (2005). A Strategic Approach to Financing Public Transport Through Property Values. *Public Money & Management* **25**, 147–154. doi: 10.1111/j.1467-9302.2005.00467.x.

Escobedo F., S. Varela, M. Zhao, J.E. Wagner, and W. Zipperer (2010). Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. *Environmental Science & Policy* **13**, 362–372. doi: 10.1016/j.envsci.2010.03.009, ISSN: 1462-9011.

Ewing R.H. (1997). *Transportation & Land Use Innovations: When You Can't Pave Your Way out of Congestion*. American Planning Association, Chicago, Ill., 106 pp. ISBN: 9781884829123.

Ewing R., and S.J. Brown (2009). *U.S. Traffic Calming Manual*. American Planning Association, Chicago, IL, 236 pp. ISBN: 9781932364613.

Ewing R., and R. Cervero (2001). Travel and the Built Environment: A Synthesis. *Transportation Research Record* **1780**, 87–114. doi: 10.3141/1780-10, ISSN: 0361-1981.

Ewing R., and R. Cervero (2010). Travel and the Built Environment: A Meta-analysis. *Journal of the American Planning Association* **76**, 265–294. doi: 10.1080/01944361003766766.

Ewing R., M. Deanna, and S.-C. Li (1996). Land Use Impacts on Trip Generation Rates. *Transportation Research Record: Journal of the Transportation Research Board* **1518**, 1–6. doi: 10.3141/1518-01.

Ewing R., M. Greenwald, M. Zhang, J. Walters, M. Feldman, R. Cervero, and J. Thomas (2009). *Measuring the Impact of Urban Form and Transit Access on Mixed Use Site Trip Generation rates—Portland Pilot Study*. U.S. Environmental Protection Agency, Washington, DC.

Ewing R., R. Pendall, and D. Chen (2003). Measuring Sprawl and Its Transportation Impacts. *Transportation Research Record: Journal of the Transportation Research Board* **1831**, 175–183. doi: 10.3141/1831-20.

Fan Y. (2007). *The built environment, activity space, and time allocation: An activity-based framework for modeling the land use and travel connection*. University of North Carolina, Chapel Hill, NC, 189 pp.

Fang H.A. (2008). A discrete-continuous model of households' vehicle choice and usage, with an application to the effects of residential density. *Transportation Research Part B: Methodological* **42**, 736–758. ISSN: 0191-2615.

Fargione J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne (2008). Land Clearing and the Biofuel Carbon Debt. *Science* **319**, 1235–1238. doi: 10.1126/science.1152747, ISSN: 0036-8075, 1095–9203.

Farvacque C., and P. McAuslan (1992). *Reforming Urban Land Policies and Institutions in Developing Countries*. World Bank, Washington, D.C., 105 pp. ISBN: 9786610015894.

Fekade W. (2000). Deficits of formal urban land management and informal responses under rapid urban growth, an international perspective. *Habitat International* **24**, 127–150. doi: 10.1016/S0197-3975(99)00034-X, ISSN: 01973975.

Feldman M.P., and D.B. Audretsch (1999). Innovation in cities: Science-based diversity, specialization and localized competition. *European Economic Review* **43**, 409–429. doi: 10.1016/S0014-2921(98)00047-6, ISSN: 00142921.

Feng K., Y.L. Siu, D. Guan, and K. Hubacek (2012). Analyzing Drivers of Regional Carbon Dioxide Emissions for China. *Journal of Industrial Ecology* **16**, 600–611. doi: 10.1111/j.1530-9290.2012.00494.x, ISSN: 1530-9290.

Fensham P., and B. Gleeson (2003). Capturing Value for Urban Management: A New Agenda for Betterment. *Urban Policy and Research* **21**, 93–112. doi: 10.1080/0811114032000062164, ISSN: 0811-1146.

Ferrell C., M. Carroll, B. Appleyard, D. Reinke, R. Dowling, H.S. Levinson, E. Deakin, and R. Cervero (2011). *Reinventing the Urban Interstate: A New Paradigm for Multimodal Corridors*. Transportation Research Board, Washington, D.C., 148 pp. Available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_145.pdf.

Fischel W. (1999). Does the American Way of Zoning Cause the Suburbs of Metropolitan Areas to Be Too Spread Out? In: *Governance and Opportunity in Metropolitan America*. A.A. Altshuler, W. Morrill, H. Wolman, F. Mitchell, (eds.), National Academies Press, Washington, D.C., pp. 151–191. ISBN: 0-309-51967-5.

Foletta N., and S. Field (2011). *Europe's Vibrant New Low Car(bon) Communities*. Institute of Transportation and Development Policy, New York, 116 pp. Available at: http://www.gwl-terrein.nl/files/artikelen/low%20carbon%20communities%20GWL%20only.pdf.

Forsyth A., J.M. Oakes, K.H. Schmitz, and M. Hearst (2007). Does Residential Density Increase Walking and Other Physical Activity? *Urban Studies* **44**, 679–697. doi: 10.1080/00420980601184729, ISSN: 0042-0980, 1360–063X.

Fouchier V. (1998). Urban Density and Mobility in the Isle-de-France. In: *Ministerio de Fomento, Proceedings of the Eight Conference on Urban and Regional Research*. Madrid, España. 285–300 pp.

Al-Fouzan S.A. (2012). Using car parking requirements to promote sustainable transport development in the Kingdom of Saudi Arabia. *Cities* **29**, 201–211. doi: 10.1016/j.cities.2011.08.009, ISSN: 02642751.

Fragkias M., J. Lobo, D. Strumsky, and K.C. Seto (2013). Does Size Matter? Scaling of CO_2 Emissions and U.S. Urban Areas (M. Convertino, Ed.). *PLOS ONE* **8**, e64727. doi: 10.1371/journal.pone.0064727, ISSN: 1932-6203.

Fraker H. (2013). *The Hidden Potential of Sustainable Neighborhoods: Lessons from Low-Carbon Communities*. Island Press, Washington, D.C., 248 pp. ISBN: 9781610914093.

Frank L.D., M.A. Andresen, and T.L. Schmid (2004). Obesity relationships with community design, physical activity, and time spent in cars. *American Journal of Preventive Medicine* **27**, 87–96. doi: 10.1016/j.amepre.2004.04.011, ISSN: 0749-3797.

Frank L.D., and P. Engelke (2005). Multiple Impacts of the Built Environment on Public Health: Walkable Places and the Exposure to Air Pollution. *International Regional Science Review* **28**, 193–216. doi: 10.1177/0160017604273853, ISSN: 0160-0176, 1552–6925.

Frank L.D., and G. Pivo (1994). Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. *Transportation Research Record* **1466**, 44–52. Available at: http://www.reconnectingamerica.org/assets/Uploads/Frank-and-Pivo.pdf.

Frank L.D., J.F. Sallis, B.E. Saelens, L. Leary, K. Cain, T.L. Conway, and P.M. Hess (2009). The Development of a Walkability Index: Application To the Neighborhood Quality of Life Study. *British Journal of Sports Medicine* **44**, 924-33. doi: 10.1136/bjsm.2009.058701, ISSN: , 14730480.

Franzsen R.C.D., and J.M. Youngman (2009). Mapping Property Taxes in Africa. *Land Lines*, pp.8–13. Lincoln Institute of Land Policy, Cambridge, MA. Available at: http://www.lincolninst.edu/pubs/1648_Mapping-Property-Taxes-in-Africa

Frolking S., T. Milliman, K.C. Seto, and M.A. Friedl (2013). A global fingerprint of macro-scale changes in urban structure from 1999 to 2009. *Environmental Research Letters* **8**, 024004. doi: 10.1088/1748-9326/8/2/024004, ISSN: 1748-9326.

Fujita M., and J.-F. Thisse (1996). Economics of agglomeration. *Journal of the Japanese and International Economies* **10**, 339–378. doi: 10.1006/jjie.1996.0021, ISSN: 08891583.

Gakenheimer R. (2011). Land use and transport in rapidly motorizing cities: contexts of controversy. In: *Urban Transport in the Developing World: A Handbook of Policy and Practice*. H.T. Dimitriou, R. Gakenheimer, (eds.), Edward Elgar Publishing, Cheltenham, pp. 40–68. ISBN: 9781849808392.

Galea S., J. Ahern, S. Rudenstine, Z. Wallace, and D. Vlahov (2005). Urban built environment and depression: a multilevel analysis. *Journal of Epidemiology and Community Health* **59**, 822–827. doi: 10.1136/jech.2005.033084, ISSN: , 1470–2738.

Ganson C. (2008). *The Transportation Greenhouse Gas Inventory: A First Step Toward City- Driven Emissions Rationalization.* University of California Transportation Center, Berkeley, CA, 15 pp. Available at: http://www.uctc.net/research/papers/879.pdf.

GEA (2012). *Global Energy Assessment—Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, 1802 pp. ISBN: 9781 10700 5198.

Gehl J. (2010). *Cities for People*. Island Press, Washington D.C., 288 pp. ISBN: 9781597269841.

Gennaio M.-P., A.M. Hersperger, and M. Bürgi (2009). Containing urban sprawl—Evaluating effectiveness of urban growth boundaries set by the Swiss Land Use Plan. *Land Use Policy* **26**, 224–232. doi: 10.1016/j.landusepol.2008.02.010, ISSN: 02648377.

Gill S.E., J.F. Handley, A.R. Ennos, and S. Pauleit (2007). Adapting Cities for Climate Change: The Role of the Green Infrastructure. *Built Environment* **33**, 115–133. doi: 10.2148/benv.33.1.115.

Glaeser E. (2011). *Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier and Happier*. Penguin, New York, 352 pp. ISBN: 0143120549.

Glaeser E.L., J. Gyourko, and R.E. Saks (2006). Urban growth and housing supply. *Journal of Economic Geography* **6**, 71–89. doi: 10.1093/jeg/lbi003, ISSN: 1468-2702, 1468–2710.

Glaeser E.L., and M.E. Kahn (2004). Sprawl and Urban Growth. In: *Handbook of Regional and Urban Economics*. J.V. Henderson, J.F. Thisse, (eds.), Elsevier, pp. 2481–2527. doi: 10.1016/S1574-0080(04)80013-0, ISBN: 9780444509673.

Glaeser E.L., and M.E. Kahn (2010). The greenness of cities: Carbon dioxide emissions and urban development. *Journal of Urban Economics* **67**, 404–418. doi: 10.1016/j.jue.2009.11.006, ISSN: 0094-1190.

Glaeser E.L., J. Kolko, and A. Saiz (2001). Consumer city. *Journal of Economic Geography* **1**, 27–50. doi: 10.1093/jeg/1.1.27, ISSN: 1468-2702.

Gomi K., K. Shimada, and Y. Matsuoka (2010). A low-carbon scenario creation method for a local-scale economy and its application in Kyoto city. *Energy Policy* **38**, 4783–4796. doi: 10.1016/j.enpol.2009.07.026, ISSN: 0301-4215.

Goodwin P.B. (1996). Empirical evidence on induced traffic. *Transportation* **23**, 35–54. doi: 10.1007/BF00166218.

Goodwin P., C. Hass-Klau, and S. Cairns (1998). Evidence on the Effects of Road Capacity Reductions on Traffic Levels. *Traffic Engineering and Control* **39**, 348–354. ISSN: 0041-0683.

Gordon D.L.A. (2001). The Resurrection of Canary Wharf. *Planning Theory & Practice* **2**, 149–168. doi: 10.1080/14649350120068777, ISSN: 1464-9357.

Gordon P., H.W. Richardson, and M.-J. Jun (1991). The Commuting Paradox Evidence from the Top Twenty. *Journal of the American Planning Association* **57**, 416–420. doi: 10.1080/01944369108975516, ISSN: 0194-4363.

Gore C., P. Robinson, and R. Stren (2009). Governance and Climate Change: Assessing and Learning from Canadian Cities. In: Hoornweg D, ed. In: *Cities and Climate Change: Responding to an Urgent Agenda*. World Bank, Marseille. 498–523 pp.

Government of NCT of Delhi (2010). *State of Environment Report for Delhi, 2010*. Department of Environment and Forests, Government of NCT of Delhi, New Delhi, 126 pp. Available at: http://www.indiaenvironmentportal.org.in/files/SoEDelhi2010.pdf.

Greenwald M.J. (2009). SACSIM modeling-elasticity results: Draft.

Grubler A., X. Bai, T. Buettner, S. Dhakal, D. Fisk, T. Ichinose, J. Keirstead, G. Sammer, D. Satterthwaite, N. Schulz, N. Shah, J. Steinberger, and H. Weisz (2012). Urban Energy Systems. In: *Global Energy Assessment: Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 1307–1400.

Grubler A., B. O'Neill, K. Riahi, V. Chirkov, A. Goujon, P. Kolp, I. Prommer, S. Scherbov, and E. Slentoe (2007). Regional, national, and spatially explicit scenarios of demographic and economic change based on SRES. *Technological Forecasting and Social Change* **74**, 980–1029. doi: 10.1016/j.techfore.2006.05.023, ISSN: 0040-1625.

Grubler A., and N. Schulz (2013). Urban energy use. In: *Energizing Sustainable Cities: Assessing Urban Energy*. A. Grubler, D. Fisk, (eds.), Routledge, Oxford, UK; New York, USA, pp. 57–70. ISBN: 9781849714396.

GTZ (2009). *Urban Transport and Climate Change Action Plans. An Overview*. Federal Ministry for Economic Cooperation and Development, Germany, 20 pp.

Guan D., K. Hubacek, C. L. Weber, G. P. Peters, and D. M. Reiner (2008). The drivers of Chinese CO_2 emissions from 1980 to 2030. *Global Environmental Change* **18**, 626–634. doi: 10.1016/j.gloenvcha.2008.08.001, ISSN: 0959-3780.

Guan D., G. P. Peters, C. L. Weber, and K. Hubacek (2009). Journey to world top emitter: An analysis of the driving forces of China's recent CO_2 emissions surge. *Geophysical Research Letters* **36**, 1–5. doi: 10.1029/2008GL036540, ISSN: 1944-8007.

Guhathakurta S., and P. Gober (2007). The Impact of the Phoenix Urban Heat Island on Residential Water Use. *Journal of the American Planning Association* **73**, 317–329. doi: 10.1080/01944360708977980, ISSN: 0194-4363.

Güneralp B., and K. C. Seto (2012). Can gains in efficiency offset the resource demands and CO_2 emissions from constructing and operating the built environment? *Applied Geography* **32**, 40–50. doi: 10.1016/j.apgeog.2010.11.011, ISSN: 01436228.

Guo Z., A. W. Agrawal, and J. Dill (2011). Are Land Use Planning and Congestion Pricing Mutually Supportive? *Journal of the American Planning Association* **77**, 232–250. doi: 10.1080/01944363.2011.592129, ISSN: 0194-4363.

Guo J., H. Liu, Y. Jiang, D. He, Q. Wang, F. Meng, and K. He (2013). Neighborhood form and CO_2 emission: evidence from 23 neighborhoods in Jinan, China. *Frontiers of Environmental Science & Engineering* **8**, 79–88. doi: 10.1007/s11783-013-0516-1, ISSN: 2095-2201, 2095–221X.

Guo Z., and S. Ren (2013). From Minimum to Maximum: Impact of the London Parking Reform on Residential Parking Supply from 2004 to 2010? *Urban Studies* **50**, 1183–1200. doi: 10.1177/0042098012460735.

Gurney K. R., I. Razlivanov, Y. Song, Y. Zhou, B. Benes, and M. Abdul-Massih (2012). Quantification of Fossil Fuel CO_2 Emissions on the Building/Street Scale for a Large U.S. City. *Environmental Science & Technology* **46**, 12194–12202. doi: 10.1021/es3011282, ISSN: 0013-936X.

Gutman P. (2007). Ecosystem services: Foundations for a new rural–urban compact. *Ecological Economics* **62**, 383–387. doi: 10.1016/j.ecolecon.2007.02.027, ISSN: 0921-8009.

Guy S., and S. Marvin (1996). Transforming urban infrastructure provision—The emerging logic of demand side management. *Policy Studies* **17**, 137–147. doi: 10.1080/01442879608423701, ISSN: 0144-2872.

Hack G., E. Birch, P. H. Sedway, and M. Silver (Eds.) (2009). *Local Planning: Contemporary Principles and Practice*. International City/County Management Association, Washington, D. C., 496 pp. ISBN: 9780873261487.

Hagman D. G., and D. J. Misczynski (1978). *Windfalls for Wipeouts: Land Value Capture and Compensation*. American Society Planning Association, Chicago, 660 pp. ISBN: 9780918286116.

Hall P. (1993). Forces Shaping Urban Europe. *Urban Studies* **30**, 883–898. doi: 10.1080/00420989320080831, ISSN: 0042-0980, 1360–063X.

Hall P. G. (1996). *Cities of Tomorrow: An Intellectual History of Urban Planning and Design in the Twentieth Century*. Blackwell Publishers, Oxford, UK ; Cambridge, MA, 502 pp. ISBN: 063119942X.

Han H., S.-K. Lai, A. Dang, Z. Tan, and C. Wu (2009). Effectiveness of urban construction boundaries in Beijing: an assessment. *Journal of Zhejiang University SCIENCE A* **10**, 1285–1295. doi: 10.1631/jzus.A0920317, ISSN: 1673-565X, 1862–1775.

Handy S. (1996). Methodologies for exploring the link between urban form and travel behavior. *Transportation Research Part D: Transport and Environment* **1**, 151–165. doi: 10.1016/S1361-9209(96)00010-7, ISSN: 1361-9209.

Handy S. (2005). Smart Growth and the Transportation-Land Use Connection: What Does the Research Tell Us? *International Regional Science Review* **28**, 146–167. doi: 10.1177/0160017604273626, ISSN: 0160-0176, 1552–6925.

Handy S., M. G. Boarnet, R. Ewing, and R. E. Killingsworth (2002). How the built environment affects physical activity: Views from urban planning. *American Journal of Preventive Medicine* **23**, 64–73. doi: 10.1016/S0749-3797(02)00475-0, ISSN: 0749-3797.

Hankey S., and J. D. Marshall (2010). Impacts of urban form on future US passenger-vehicle greenhouse gas emissions. *Energy Policy* **38**, 4880–4887. doi: 10.1016/j.enpol.2009.07.005, ISSN: 0301-4215.

Hansen W. G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners* **25**, 73–76. doi: 10.1080/01944365908978307, ISSN: 0002-8991.

Hansen M., and Y. Huang (1997). Road supply and traffic in California urban areas. *Transportation Research Part A: Policy and Practice* **31**, 205–218. doi: 10.1016/S0965-8564(96)00019-5.

Hao L., J. Keirstead, N. Samsatli, W. Shah, and W. Long (2011). Application of a novel, optimisation-based toolkit ("syncity") for urban energy system design in Shanghai Lingang New City. *Energy Education Science and Technology A: Energy Science and Research* **28**, 311–318.

Harlan S. L., and D. M. Ruddell (2011). Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. *Current Opinion in Environmental Sustainability* **3**, 126–134. doi: 10.1016/j.cosust.2011.01.001, ISSN: 1877-3435.

Harris J. R., and M. P. Todaro (1970). Migration, Unemployment & Development: A Two-Sector Analysis. *American Economic Review* **60**, 126–42. Available at: http://www.jstor.org/stable/1807860.

Hartshorne R. (1933). Geographic and Political Boundaries in Upper Silesia. *Annals of the Association of American Geographers* **23**, 195–228. doi: 10.1080/00045603309357073, ISSN: 0004-5608.

Hass-Klau C. (1993). Impact of pedestrianization and traffic calming on retailing: A review of the evidence from Germany and the UK. *Transport Policy* **1**, 21–31. doi: 10.1016/0967-070X(93)90004-7.

Hausman J. A. (1979). Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables. *The Bell Journal of Economics* **10**, 33–54. doi: 10.2307/3003318, ISSN: 0361-915X.

Heath G. W., R. C. Brownson, J. Kruger, R. Miles, K. E. Powell, and L. T. Ramsey (2006). The effectiveness of urban design and land use and transport policies and practices to increase physical activity: a systematic review. *Journal of Physical Activity & Health* **3**, S55–S76. Available at: http://www.aapca3.org/resources/archival/060306/jpah.pdf

Heijungs R., and S. Suh (2010). *The Computational Structure of Life Cycle Assessment*. Springer, Dordrecht, NL; Boston, US, 256 pp. ISBN: 9789048160419.

Heinonen J., and S. Junnila (2011a). Implications of urban structure on carbon consumption in metropolitan areas. *Environmental Research Letters* **6**, 014018. doi: 10.1088/1748-9326/6/1/014018, ISSN: 1748-9326.

Heinonen J., and S. Junnila (2011b). Case study on the carbon consumption of two metropolitan cities. *The International Journal of Life Cycle Assessment* **16**, 569–579. doi: 10.1007/s11367-011-0289-3, ISSN: 0948-3349.

Heinonen J., and S. Junnila (2011c). A Carbon Consumption Comparison of Rural and Urban Lifestyles. *Sustainability* **3**, 1234–1249. doi: 10.3390/su3081234, ISSN: 2071-1050.

Heinonen J., R. Kyrö, and S. Junnila (2011). Dense downtown living more carbon intense due to higher consumption: a case study of Helsinki. *Environmental Research Letters* **6**, 034034. doi: 10.1088/1748-9326/6/3/034034, ISSN: 1748-9326.

Henderson V. (2003). The Urbanization Process and Economic Growth: The So-What Question. *Journal of Economic Growth* **8**, 47–71. doi: 10.1023/A:1022860800744, ISSN: 1381-4338, 1573–7020.

Henderson J.V., A. Kuncoro, and M. Turner (1995). Industrial Development in Cities. *Journal of Political Economy* **103**, 1067–1090. doi: 10.1086/262013, ISSN: 0022-3808.

Heres-Del-Valle D., and D. Niemeier (2011). CO_2 emissions: Are land-use changes enough for California to reduce VMT? Specification of a two-part model with instrumental variables. *Transportation Research Part B: Methodological* **45**, 150–161. doi: 10.1016/j.trb.2010.04.001, ISSN: 0191-2615.

Heynen N., H.A. Perkins, and P. Roy (2006). The Political Ecology of Uneven Urban Green Space. *Urban Affairs Review* **42**, 3–25. doi: 10.1177/1078087406290729.

Hidalgo D., and L. Gutiérrez (2013). BRT and BHLS around the world: Explosive growth, large positive impacts and many issues outstanding. *Research in Transportation Economics* **39**, 8–13. doi: 10.1016/j.retrec.2012.05.018, ISSN: 0739-8859.

Hidle K., A.A. Farsund, and H.K. Lysgård (2009). Urban–Rural Flows and the Meaning of Borders Functional and Symbolic Integration in Norwegian City-Regions. *European Urban and Regional Studies* **16**, 409–421. doi: 10.1177/0969776409340863, ISSN: 0969-7764, 1461–7145.

Hillman T., and A. Ramaswami (2010). Greenhouse Gas Emission Footprints and Energy Use Benchmarks for Eight U.S. Cities. *Environmental Science & Technology* **44**, 1902–1910. doi: 10.1021/es9024194, ISSN: 0013-936X.

Hirt S. (2007). The Devil Is in the Definitions: Contrasting American and German Approaches to Zoning. *Journal of the American Planning Association* **73**, 436–450. doi: 10.1080/01944360708978524, ISSN: 0194-4363, 1939–0130.

Hirt S. (2012). Mixed Use by Default: How the Europeans (Don't) Zone. *Journal of Planning Literature* **27**, 375–393. doi: 10.1177/0885412212451029, ISSN: 0885-4122, 1552–6593.

Hoch C., L.C. Dalton, and F.S. So (Eds.) (2000). *The Practice of Local Government Planning*. Published for the ICMA Training Institute by the International City/County Management Association, Washington, D.C., ISBN: 0873261712 9780873261715.

Hoekman S.K. (2009). Biofuels in the U.S.—Challenges and Opportunities. *Renewable Energy* **34**, 14–22. doi: 10.1016/j.renene.2008.04.030, ISSN: 0960-1481.

Hofman P.S. (2007). Transition paths for the electricity system. Three alternative electricity futures based upon the sociotechnical scenario methodology. In: *Visions on the Development of the Electricity System*. Eindhoven.

Holgate C. (2007). Factors and Actors in Climate Change Mitigation: A Tale of Two South African Cities. *Local Environment* **12**, 471–484. doi: 10.1080/13549830701656994, ISSN: 1354-9839.

Holtzclaw J., R. Clear, H. Dittmar, D. Goldstein, and P. Haas (2002). Location Efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use—Studies in Chicago, Los Angeles and San Francisco. *Transportation Planning and Technology* **25**, 1–27. doi: 10.1080/03081060290032033, ISSN: 0308-1060, 1029–0354.

Hong Y., and B. Needham (2007). *Analyzing Land Readjustment: Economics, Law, and Collective Action*. Lincoln Institute of Land Policy, Cambridge, MA, 203 pp. ISBN: 9781558441644.

Hoornweg D., L. Sugar, and C.L.T. Gómez (2011). Cities and greenhouse gas emissions: moving forward. *Environment and Urbanization* **23**, 207–227. doi: 10.1177/0956247810392270, ISSN: 0956-2478, 1746–0301.

Hoppenbrouwer E., and E. Louw (2005). Mixed-use development: Theory and practice in Amsterdam's Eastern Docklands. *European Planning Studies* **13**, 967–983. doi: 10.1080/09654310500242048, ISSN: 0965-4313.

Horner M., and A. Murray (2003). A Multi-objective Approach to Improving Regional Jobs-Housing Balance. *Regional Studies* **37**, 135–146. doi: 10.1080/0034340022000057514, ISSN: 0034-3404, 1360–0591.

Horvath A. (2004). Construction Materials and the Environment. *Annual Review of Environment and Resources* **29**, 181–204. doi: 10.1146/annurev.energy.29.062403.102215.

Hou Q., and S.-M. Li (2011). Transport infrastructure development and changing spatial accessibility in the Greater Pearl River Delta, China, 1990–2020. *Journal of Transport Geography* **19**, 1350–1360. doi: 10.1016/j.jtrangeo.2011.07.003, ISSN: 09666923.

Hurtt G., L. Chini, S. Frolking, R. Betts, J. Feddema, G. Fischer, J. Fisk, K. Hibbard, R. Houghton, A. Janetos, C. Jones, G. Kindermann, T. Kinoshita, K. Klein Goldewijk, K. Riahi, E. Shevliakova, S. Smith, E. Stehfest, A. Thomson, P. Thornton, D. van Vuuren, and Y. Wang (2011). Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands. *Climatic Change* **109**, 117–161. doi: 10.1007/s10584-011-0153-2, ISSN: 0165-0009.

Hymel K.M., K.A. Small, and K.V. Dender (2010). Induced demand and rebound effects in road transport. *Transportation Research Part B: Methodological* **44**, 1220–1241. doi: 10.1016/j.trb.2010.02.007, ISSN: 01912615.

Ibrahim N., L. Sugar, D. Hoornweg, and C. Kennedy (2012). Greenhouse gas emissions from cities: comparison of international inventory frameworks. *Local Environment* **17**, 223–241. doi: 10.1080/13549839.2012.660909, ISSN: 1354-9839.

ICLEI (2009). *International Local Government GHG Emission Analysis Protocol (IEAP): Version 1.0*. ICLEI—Local Governments for Sustainability, Bonn, Germany, 56 pp. Available at: http://carbonn.org/fileadmin/user_upload/carbonn/Standards/IEAP_October2010_color.pdf.

ICLEI, C40, and WRI (2012). *Global Protocol for Community-Scale GHG Emissions*. World Resources Institute and World Business Council for Sustainable Development, Washington, D.C. Conches-Geneva, Switzerland, 14 pp. Available at: http://www.ghgprotocol.org/files/ghgp/GPC_PilotVersion_1.0_May2012_20120514.pdf.

IEA (2008). *World Energy Outlook 2008 Edition*. International Energy Agency, Paris, France, 578 pp. ISBN: 9789264045606. Available at: http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo2008.pdf.

IEA (2010). *Energy Poverty: How to Make Modern Energy Access Universal?* OECD/IEA, Paris, France, 52 pp. Available at: http://www.se4all.org/wp-content/uploads/2013/09/Special_Excerpt_of_WEO_2010.pdf.

IEA (2012). *World Energy Outlook 2012*. OECD Publishing, Paris, Available at: http://www.iea.org/publications/freepublications/publication/English.pdf.

IEA (2013). *Redrawing the Energy Climate Map*. International Energy Agency (IEA), Paris, France, 132 pp. Available at: http://www.worldenergyoutlook.org/energyclimatemap/.

IIASA (2009). GGI Scenario Database Version 2.0.1. Available at: http://www.iiasa.ac.at/Research/GGI/DB.

Inglehart R. (1997). *Modernization and Postmodernization: Cultural, Economic, and Political Change in 43 Societies*. Princeton University Press, Princeton, N.J., ISBN: 9780691011806.

Ingram D.R. (1971). The concept of accessibility: A search for an operational form. *Regional Studies* **5**, 101–107. doi: 10.1080/09595237100185131, ISSN: 0034-3404, 1360–0591.

IPCC (2011). *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp.

Istrate E., and C.A. Nadeau (2012). *Global MetroMonitor 2012: Slowdown, Recovery, and Interdependence*. Brookings Institution, Washington, D.C., 52 pp. Available at: http://www.brookings.edu/~/media/research/files/reports/2012/11/30%20global%20metro%20monitor/30%20global%20monitor.

Jaccard M., L. Failing, and T. Berry (1997). From equipment to infrastructure: community energy management and greenhouse gas emission reduction. *Energy Policy* **25**, 1065–1074. doi: 10.1016/S0301-4215(97)00091-8, ISSN: 0301-4215.

Jaccard M., and N. Rivers (2007). Heterogeneous capital stocks and the optimal timing for CO_2 abatement. *Resource and Energy Economics* **29**, 1–16. doi: 10.1016/j.reseneeco.2006.03.002, ISSN: 0928-7655.

Jacob D.J., and D.A. Winner (2009). Effect of climate change on air quality. *Atmospheric Environment* **43**, 51–63. doi: 10.1016/j.atmosenv.2008.09.051, ISSN: 1352-2310.

Jewell J., A. Cherp, V. Vinichenko, N. Bauer, T. Kober, D. McCollum, D. van Vuuren, and B. vander Zwaan (2013). Energy security of China, India, the EU, and the US under long-term low-carbon scenarios: Results from six IAMs. In: *Climate Change Economics*. Paris, France.

Jiang Z., and B. Lin (2012). China's energy demand and its characteristics in the industrialization and urbanization process. *Energy Policy* **49**, 608–615. doi: 10.1016/j.enpol.2012.07.002, ISSN: 03014215.

Jiang L., and B.C. O'Neill (2004). The energy transition in rural China. *International Journal of Global Energy Issues* **21**, 2–26. Available at: http://inderscience.metapress.com/content/16KPY22M4U3K56VW.

Jiang L., and B.C. O'Neill (2007). Impacts of Demographic Trends on US Household Size and Structure. *Population and Development Review* **33**, 567–591. ISSN: 0098-7921.

Jim C.Y., and W.Y. Chen (2009). Ecosystem services and valuation of urban forests in China. *Cities* **26**, 187–194. doi: 10.1016/j.cities.2009.03.003, ISSN: 0264-2751.

Jo H. (2002). Impacts of urban greenspace on offsetting carbon emissions for middle Korea. *Journal of Environmental Management* **64**, 115–126. doi: 10.1006/jema.2001.0491, ISSN: 03014797.

Johnson G.T., and L.A. Hoel (1985). *An Inventory of Value Capture Techniques for Transportation*. University of Virginia, Charlottesville, VA, 39 pp.

Jones D.W. (2004). Urbanization and Energy. In: *Encyclopedia of Energy*. C.J. Cleveland, (ed.), Elsevier, Amsterdam, pp. 329–335. ISBN: 9780121764807.

Jones C.M., and D.M. Kammen (2011). Quantifying Carbon Footprint Reduction Opportunities for U.S. Households and Communities. *Environmental Science & Technology* **45**, 4088–4095. doi: 10.1021/es102221h, ISSN: 0013-936X, 1520–5851.

Jun M.-J., and C.-H.C. Bae (2000). Estimating the Commuting Costs of Seoul's Greenbelt. *International Regional Science Review* **23**, 300–315.

Jun M.-J., and J.-W. Hur (2001). Commuting costs of "leap-frog" newtown development in Seoul. *Cities* **18**, 151–158. doi: 10.1016/S0264-2751(01)00007-5, ISSN: 0264-2751.

Junge J.R., and D. Levinson (2012). Financing transportation with land value taxes: Effects on development intensity. *Journal of Transport and Land Use* **5**, 49–63. doi: 10.5198/jtlu.v5i1.148, ISSN: 1938-7849.

Kahn M.E. (2009). Urban Growth and Climate Change. *Annual Review of Resource Economics* **1**, 333–350. doi: 10.1146/annurev.resource.050708.144249.

Kang C.D., and R. Cervero (2009). From Elevated Freeway to Urban Greenway: Land Value Impacts of the CGC Project in Seoul, Korea. *Urban Studies* **46**, 2771–2794.

Kawada T. (2011). Noise and Health—Sleep Disturbance in Adults. *Journal of Occupational Health* **53**, 413–416. doi: 10.1539/joh.11-0071-RA.

Kaya Y. (1990). Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. In: *Response Strategies Working Group*. Paris.

Keirstead J., and N. Shah (2013). Urban energy systems planning, design and implementation. In: *Energizing Sustainable Cities: Assessing Urban Energy*. A. Grubler, D. Fisk, (eds.), Routledge, pp. 155–162. ISBN: 9781849714396.

Kelly E.D. (1993). *Planning, Growth, and Public Facilities: A Primer for Local Officials*. American Planning Association, Planning Advisory Service, Chicago, IL, 30 pp.

Kennedy C., and J. Corfee-Morlot (2013). Past performance and future needs for low carbon climate resilient infrastructure—An investment perspective. *Energy Policy* **59**, 773–783. doi: j.enpol.2013.04.031.

Kennedy C., S. Demoullin, and E. Mohareb (2012). Cities reducing their greenhouse gas emissions. *Energy Policy* **49**, 774–777. doi: 10.1016/j.enpol.2012.07.030, ISSN: 0301-4215.

Kennedy C., E. Miller, A. Shalaby, H. Maclean, and J. Coleman (2005). The Four Pillars of Sustainable Urban Transportation. *Transport Reviews* **25**, 393–414. doi: 10.1080/01441640500115835, ISSN: 0144-1647, 1464–5327.

Kennedy C., A. Ramaswami, S. Carney, and S. Dhakal (2011). Greenhouse gas emission baselines for global cities and metropolitan regions. Urban Development Series. In: *Cities and Climate Change: Responding to an Urgent Agenda*. D. Hoornweg, M. Freire, M.J. Lee, P. Bhada-Tata, B. Yuen, (eds.), The World Bank, Washington, D.C., USISBN: 978-0-8213-8493-0.

Kennedy C., J. Steinberger, B. Gasson, Y. Hansen, T. Hillman, M. Havránek, D. Pataki, A. Phdungsilp, A. Ramaswami, and G.V. Mendez (2009). Greenhouse Gas Emissions from Global Cities. *Environmental Science & Technology* **43**, 7297–7302. doi: 10.1021/es900213p, ISSN: 0013-936X.

Kennedy C., J. Steinberger, B. Gasson, Y. Hansen, T. Hillman, M. Havránek, D. Pataki, A. Phdungsilp, A. Ramaswami, and G.V. Mendez (2010). Methodology for inventorying greenhouse gas emissions from global cities. *Energy Policy* **38**, 4828–4837. doi: 10.1016/j.enpol.2009.08.050, ISSN: 0301-4215.

Kenworthy J.R., and F.B. Laube (1999). Patterns of automobile dependence in cities: an international overview of key physical and economic dimensions with some implications for urban policy. *Transportation Research Part A: Policy and Practice* **33**, 691–723. doi: 10.1016/S0965-8564(99)00006-3.

Kern K., and H. Bulkeley (2009). Cities, Europeanization and multi-level governance: Governing climate change through transnational municipal networks. *Journal of Common Market Studies* **47**, 309–332. doi: 10.1111/j.1468-5965.2009.00806.x, ISSN: 00219886.

Keyfitz N. (1980). Do Cities Grow by Natural Increase or by Migration? *Geographical Analysis* **12**, 142–156. doi: 10.1111/j.1538-4632.1980.tb00024.x, ISSN: 1538-4632.

Khattak A.J., and D. Rodriguez (2005). Travel behavior in neo-traditional neighborhood developments: A case study in USA. *Transportation Research Part A: Policy and Practice* **39**, 481–500. doi: 10.1016/j.tra.2005.02.009, ISSN: 0965-8564.

Kinney P.L., M.G. Gichuru, N. Volavka-Close, N. Ngo, P.K. Ndiba, A. Law, A. Gachanja, S.M. Gaita, S.N. Chillrud, and E. Sclar (2011). Traffic Impacts on PM2.5 Air Quality in Nairobi, Kenya. *Environmental Science & Policy* **14**, 369–378. doi: 10.1016/j.envsci.2011.02.005, ISSN: 1462-9011.

Kitamura R., T. Akiyama, T. Yamamoto, and T. Golob (2001). Accessibility in a Metropolis: Toward a Better Understanding of Land Use and Travel. *Transportation Research Record* **1780**, 64–75. doi: 10.3141/1780-08, ISSN: 0361-1981.

Kleiber M. (1961). *The Fire of Life: An Introduction to Animal Energetics*. Wiley, New York, NY, 454 pp.

Knudsen B., R. Florida, K. Stolarick, and G. Gates (2008). Density and Creativity in U.S. Regions. *Annals of the Association of American Geographers* **98**, 461–478. doi: 10.1080/00045600701851150, ISSN: 0004-5608, 1467–8306.

Kockelman K. (1997). Travel Behavior as Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from San Francisco Bay Area. *Transportation Research Record: Journal of the Transportation Research Board* **1607**, 116–125. doi: 10.3141/1607-16.

Kodransky M., and G. Hermann (2011). *Europe's Parking U-Turn: From Accommodation to Regulation*. Institute for Transport and Development Policy, New York, USA, 84 pp. Available at: http://www.itdp.org/library/publications/european-parking-u-turn-from-accommodation-to-regulation.

Koehn P.H. (2008). Underneath Kyoto: emerging subnational government initiatives and incipient issue-bundling opportunities in China and the United States. *Global Environmental Politics* **8**, 53–77. doi: 10.1162/glep.2008.8.1.53.

Kondratieff N.D., and W.F. Stolper (1935). The Long Waves in Economic Life. *The Review of Economics and Statistics* **17**, 105–115. doi: 10.2307/1928486, ISSN: 0034-6535.

Koster H.R.A., and J. Rouwendal (2012). The Impact Of Mixed Land Use On Residential Property Values. *Journal of Regional Science* **52**, 733–761. Available at: http://ideas.repec.org/a/bla/jregsc/v52y2012i5p733–761.html.

Kostof S. (1992). *The City Assembled: The Elements of Urban Form Through History*. Little, Brown, Boston, 320 pp. ISBN: 0821219308 9780821219300.

Kostof S., and R. Tobias (1999). *The City Shaped: Urban Patterns and Meanings Through History*. Thames & Hudson, New York, 352 pp. ISBN: 0821220160 9780821220160.

Kousky C., and S.H. Schneider (2003). Global climate policy: will cities lead the way? *Climate Policy* **3**, 359–372. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=egh&AN=17053210&site=ehost-live.

Krause R.M. (2011a). Symbolic or substantive policy? Measuring the extent of local commitment to climate protection. *Environment and Planning C: Government and Policy* **29**, 46–62. doi: 10.1068/c09185, ISSN: 0263774X.

Krause R.M. (2011b). Policy Innovation, Intergovernmental Relations, and the Adoption of Climate Protection Initiatives by U.S. Cities. *Journal of Urban Affairs* **33**, 45–60. doi: 10.1111/j.1467-9906.2010.00510.x, ISSN: 1467-9906.

Krause R.M. (2011c). An assessment of the greenhouse gas reducing activities being implemented in US cities. *Local Environment* **16**, 193–211. doi: 10.1080/13549839.2011.562491, ISSN: 1354-9839.

Krey V., B.C. O'Neill, B. van Ruijven, V. Chaturvedi, V. Daioglou, J. Eom, L. Jiang, Y. Nagai, S. Pachauri, and X. Ren (2012). Urban and rural energy use and carbon dioxide emissions in Asia. *Energy Economics* **34**, S272–S283. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0–84870553992&partnerID=40&md5=000fc5bd314e96ec58bf9aceb09d78ec.

Krizek K.J. (2003). Residential Relocation and Changes in Urban Travel: Does Neighborhood-Scale Urban Form Matter? *Journal of the American Planning Association* **69**, 265–281. doi: 10.1080/01944360308978019, ISSN: 0194-4363, 1939–0130.

Kronenberg T. (2009). The impact of demographic change on energy use and greenhouse gas emissions in Germany. *Ecological Economics* **68**, 2637–2645. doi: 10.1016/j.ecolecon.2009.04.016, ISSN: 0921-8009.

Krugman P. (1996). Confronting the Mystery of Urban Hierarchy. *Journal of the Japanese and International Economies* **10**, 399–418. doi: 10.1006/jjie.1996.0023, ISSN: 0889-1583.

Kühn M. (2003). Greenbelt and Green Heart: separating and integrating landscapes in European city regions. *Landscape and Urban Planning* **64**, 19–27. Available at: http://www.sciencedirect.com/science/article/pii/S0169204602001986.

Kumar N. (2004). Changing geographic access to and locational efficiency of health services in two Indian districts between 1981 and 1996. *Social Science & Medicine* **58**, 2045–2067. doi: 10.1016/j.socscimed.2003.08.019, ISSN: 0277-9536.

Kunstler J.H. (1998). *Home from Nowhere: Remaking Our Everyday World For the 21st Century*. Simon and Schuster, New York, US, 326 pp. ISBN: 0684837374.

Kuzmyak R. (2009a). Estimating the travel benefits of blueprint land use concepts. Unpublished Manuscript, Southern California Association of Governments, Los Angeles, CA.

Kuzmyak R. (2009b). *Estimates of Point Elasticities*. Maricopa Association of Governments, Phoenix, AZ.

Kuzmyak J., C. Baber, and D. Savory (2006). Use of Walk Opportunities Index to Quantify Local Accessibility. *Transportation Research Record: Journal of the Transportation Research Board* **1977**, 145–153. doi: 10.3141/1977-19.

Ladd H. (1998). Effects of taxes on economic activity. In: *Local government tax and land use policies in the U.S.: Understanding the links*. Edward Elgar, Northampton, MA, pp. 82–101. ISBN: 1-85898-657-5.

Lam S.H., and T.D. Toan (2006). Land Transport Policy and Public Transport in Singapore. *Transportation* **33**, 171–188. doi: 10.1007/s11116-005-3049-z, ISSN: 0049-4488, 1572–9435.

Landis J., R. Cervero, and P. Hall (1991). Transit joint development in the USA: an inventory and policy assessment. *Environment and Planning C: Government and Policy* **9**, 431–452. doi: 10.1068/c090431.

de Lara M., A. de Palma, M. Kilani, and S. Piperno (2013). Congestion pricing and long term urban form: Application to Paris region. *Regional Science and Urban Economics* **43**, 282–295. doi: 10.1016/j.regsciurbeco.2012.07.007, ISSN: 01660462.

Larsen H.N., and E.G. Hertwich (2009). The case for consumption-based accounting of greenhouse gas emissions to promote local climate action. *Environmental Science & Policy* **12**, 791–798. doi: 10.1016/j.envsci.2009.07.010, ISSN: 1462-9011.

Larsen H.N., and E.G. Hertwich (2010a). Identifying important characteristics of municipal carbon footprints. *Ecological Economics* **70**, 60–66. doi: 10.1016/j.ecolecon.2010.05.001, ISSN: 0921-8009.

Larsen H.N., and E.G. Hertwich (2010b). Implementing Carbon-Footprint-Based Calculation Tools in Municipal Greenhouse Gas Inventories. *Journal of Industrial Ecology* **14**, 965–977. doi: 10.1111/j.1530-9290.2010.00295.x, ISSN: 1530-9290.

Lee C., and A.V. Moudon (2006). The 3Ds + R: Quantifying land use and urban form correlates of walking. *Transportation Research Part D: Transport and Environment* **11**, 204–215. doi: 10.1016/j.trd.2006.02.003, ISSN: 1361-9209.

Lenzen M., M. Wier, C. Cohen, H. Hayami, S. Pachauri, and R. Schaeffer (2006). A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan. *Energy* **31**, 181–207. doi: 10.1016/j.energy.2005.01.009, ISSN: 0360-5442.

LeRoy S.F., and J. Sonstelie (1983). Paradise lost and regained: Transportation innovation, income, and residential location. *Journal of Urban Economics* **13**, 67–89. doi: 10.1016/0094-1190(83)90046-3, ISSN: 0094-1190.

Levin S.A. (1992). The Problem of Pattern and Scale in Ecology: The Robert H. MacArthur Award Lecture. *Ecology* **73**, 1943–1967. doi: 10.2307/1941447, ISSN: 0012-9658.

Levine J. (1998). Rethinking Accessibility and Jobs-Housing Balance. *Journal of the American Planning Association* **64**, 133–149. doi: 10.1080/01944369808975972, ISSN: 0194-4363, 1939–0130.

Levine J. (2005). *Zoned Out: Regulation, Markets, and Choices in Transportation and Metropolitan Land Use*. Resources for the Future, Washington D.C., 223 pp. ISBN: 9781933115153.

Levine M.D., and N.T. Aden (2008). Global Carbon Emissions in the Coming Decades: The Case of China. *Annual Review of Environment and Resources* **33**, 19–38. doi: 10.1146/annurev.environ.33.012507.172124.

Levine J., and A. Inam (2004). The Market for Transportation-Land Use Integration: Do Developers Want Smarter Growth than Regulations Allow? *Transportation* **31**, 409–427. doi: 10.1023/B:PORT.0000037086.33893.9f, ISSN: 0049-4488, 1572–9435.

Li L., C. Chen, S. Xie, C. Huang, Z. Cheng, H. Wang, Y. Wang, H. Huang, J. Lu, and S. Dhakal (2010). Energy demand and carbon emissions under different development scenarios for Shanghai, China. *Energy Policy* **38**, 4797–4807. doi: 10.1016/j.enpol.2009.08.048, ISSN: 0301-4215.

Li W., and J. Huang (2010). The Conception of Transit Metropolis in Guangzhou. Institute of Electrical and Electronics Engineers (IEEE), Singapore, 817–820 pp. Available at: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5535305.

Lin J., Y. Liu, F. Meng, S. Cui, and L. Xu (2013). Using hybrid method to evaluate carbon footprint of Xiamen City, China. *Energy Policy* **58**, 220–227. doi: 10.1016/j.enpol.2013.03.007, ISSN: 0301-4215.

Lin J.-J., and A.-T. Yang (2009). Structural Analysis of How Urban Form Impacts Travel Demand: Evidence from Taipei. *Urban Studies* **46**, 1951–1967. doi: 10.1177/0042098009106017, ISSN: 0042-0980, 1360–063X.

Liu L.-C., Y. Fan, G. Wu, and Y.-M. Wei (2007). Using LMDI method to analyze the change of China's industrial CO_2 emissions from final fuel use: An empirical analysis. *Energy Policy* **35**, 5892–5900. doi: 10.1016/j.enpol.2007.07.010, ISSN: 0301-4215.

Liu Z., S. Liang, Y. Geng, B. Xue, F. Xi, Y. Pan, T. Zhang, and T. Fujita (2012). Features, trajectories and driving forces for energy-related GHG emissions from Chinese mega cites: The case of Beijing, Tianjin, Shanghai and Chongqing. *Energy* **37**, 245–254. doi: 10.1016/j.energy.2011.11.040, ISSN: 03605442.

Lotfi S., and M. Koohsari (2011). Neighborhood Walkability in a City within a Developing Country. *Journal of Urban Planning and Development* **137**, 402–408. doi: 10.1061/(ASCE)UP.1943-5444.0000085, ISSN: 0733-9488.

Lu W., C. Chen, M. Su, B. Chen, Y. Cai, and T. Xing (2013). Urban energy consumption and related carbon emission estimation: a study at the sector scale. *Frontiers of Earth Science* **7**, 480–486. doi: 10.1007/s11707-013-0363-1, ISSN: 2095-0195, 2095–0209.

Lund H., R.W. Willson, and R. Cervero (2006). A Re-Evaluation of Travel Behavior in California Tods. *Journal of Architectural & Planning Research* **23**, 247–263. ISSN: 07380895.

Lusht K.M. (1992). *The Site Value Tax and Residential Development*. Lincoln Insitute for Land Policy, Washington, D.C., 22 pp.

Lutsey N., and D. Sperling (2008). America's bottom-up climate change mitigation policy. *Energy Policy* **36**, 673–685. doi: 10.1016/j.enpol.2007.10.018, ISSN: 0301-4215.

Lwasa S. (2013). Planning innovation for better urban communities in sub-Saharan Africa: The education challenge and potential responses. *Town and Regional Planning* **60**, 38–48. ISSN: 1012-280X.

Lynch K. (1981). *A Theory of Good City Form*. MIT Press, ISBN: 9780262120852.

Ma K.-R., and D. Banister (2006). Extended Excess Commuting: A Measure of the Jobs-Housing Imbalance in Seoul. *Urban Studies* **43**, 2099–2113. doi: 10.1080/00420980600945245, ISSN: 0042-0980, 1360–063X.

MacKellar F.L., W. Lutz, C. Prinz, and A. Goujon (1995). Population, Households, and CO_2 Emissions. *Population and Development Review* **21**, 849–865. doi: 10.2307/2137777, ISSN: 0098-7921.

Macknick J. (2011). Energy and CO_2 emission data uncertainties. *Carbon Management* **2**, 189–205. doi: 10.4155/cmt.11.10, ISSN: 1758-3004.

Makido Y., S. Dhakal, and Y. Yamagata (2012). Relationship between urban form and CO_2 emissions: Evidence from fifty Japanese cities. *Urban Climate* **2**, 55–67. doi: 10.1016/j.uclim.2012.10.006, ISSN: 22120955.

Manaugh K., and T. Kreider (2013). What is mixed use? Presenting an interaction method for measuring land use mix. *Journal of Transport and Land Use* **6**, 63–72. ISSN: 1938-7849.

Mans J., E. Interrante, L. Lem, J. Mueller, and M. Lawrence (2012). Next Generation of Travel Behavior. *Journal of the Transportation Research Board* **2323**, 90–98. doi: 10.3141/2323-11, ISSN: 0361-1981.

Marcotullio P.J., J. Albrecht, and A. Sarzynski (2011). The geography of greenhouse gas emissions from within urban areas of India: a preliminary assessment. *Journal of Resources, Energy and Development* **8**, 11–35. doi: 10.3233/RED-120079.

Marcotullio P.J., A. Sarzynski, J. Albrecht, and N. Schulz (2012). The geography of urban greenhouse gas emissions in Asia: A regional analysis. *Global Environmental Change* **22**, 944–958. doi: 10.1016/j.gloenvcha.2012.07.002, ISSN: 0959-3780.

Marcotullio P.J., A. Sarzynski, J. Albrecht, N. Schulz, and J. Garcia (2013). The geography of global urban greenhouse gas emissions: an exploratory analysis. *Climatic Change*, **121**, 621–634. doi: 10.1007/s10584-013-0977-z, ISSN: 0165-0009, 1573–1480.

Markandya A., B.G. Armstrong, S. Hales, A. Chiabai, P. Criqui, S. Mima, C. Tonne, and P. Wilkinson (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: low-carbon electricity generation. *The Lancet* **374**, 2006–2015. doi: 10.1016/S0140-6736(09)61715-3, ISSN: 01406736.

Marshall J.D. (2008). Energy-efficient urban form. *Environmental Science & Technology* **42**, 3133–3137.

Martinez-Fernandez C., I. Audirac, S. Fol, and E. Cunningham-Sabot (2012). Shrinking Cities: Urban Challenges of Globalization. *International Journal of Urban and Regional Research* **36**, 213–225. doi: 10.1111/j.1468-2427.2011.01092.x, ISSN: 1468-2427.

Martinot E., A. Chaurey, D. Lew, J.R. Moreira, and N. Wamukonya (2002). Renewable Energy Markets in Developing Countries. *Annual Review of Energy and the Environment* **27**, 309–348. doi: 10.1146/annurev.energy.27.122001.083444.

Mavrogianni A., M. Davies, M. Batty, S.E. Belcher, S.I. Bohnenstengel, D. Carruthers, Z. Chalabi, B. Croxford, C. Demanuele, S. Evans, R. Giridharan, J.N. Hacker, I. Hamilton, C. Hogg, J. Hunt, M. Kolokotroni, C. Martin, J. Milner, I. Rajapaksha, I. Ridley, J.P. Steadman, J. Stocker, P. Wilkinson, and Z. Ye (2011). The comfort, energy and health implications of London's urban heat island. *Building Services Engineering Research and Technology* **32**, 35–52. doi: 10.1177/0143624410394530, ISSN: 0143-6244, 1477–0849.

Mayer C.J., and C.T. Somerville (2000). Land use regulation and new construction. *Regional Science and Urban Economics* **30**, 639–662. Available at: http://www.sciencedirect.com/science/article/pii/S0166046200000557.

McAndrews C., E. Deakin, and L. Schipper (2010). Climate Change and Urban Transportation in Latin America. *Transportation Research Record: Journal of the Transportation Research Board* **2191**, 128–135. doi: 10.3141/2191-16.

McCann B., and B. Rynne (Eds.) **(2010).** *Complete Streets: Best Policy Implementation Practices*. American Planning Association, Chicago, 141 pp. Available at: http://www.planning.org/pas/brochure/pdf/report.pdf.

McCarney P.L., H. Blanco, J. Carmin, and M. Colley (2011). Cities and Climate Change: The Challenges for Governance. In: *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*. C. Rosenzweig, W.D. Solecki, S.A. Hammer, S. Mehrotra, (eds.), Cambridge University Press, Cambridge, UK, pp. 249–269. ISBN: 978-110-700-420-7.

McCarney P.L., and R.E. Stren (2008). Metropolitan Governance: Governing in a city of cities. In: *State of the World's Cities 2008/2009 – Harmonious Cities.*. UN-HABITAT, Nairobi, Kenya, pp. 226–237. ISBN: 978-92-1-132010-7.

McCormack E., G. Scott Rutherford, and M. Wilkinson (2001). Travel Impacts of Mixed Land Use Neighborhoods in Seattle, Washington. *Transportation Research Record* **1780**, 25–32. doi: 10.3141/1780-04, ISSN: 0361-1981.

McDonald R.I. (2008). Global urbanization: can ecologists identify a sustainable way forward? *Frontiers in Ecology and the Environment* **6**, 99–104. doi: 10.1890/070038, ISSN: 1540-9295.

McDonnell S., J. Madar, and V. Been (2011). Minimum parking requirements and housing affordability in New York City. *Housing Policy Debate* **21**, 45–68. DOI:10.1080/10511482.2011.534386.

McKinsey Global Institute (2011). *Urban World: Mapping the Economic Power of Cities*. McKinsey Global Institute, 62 pp.

Mejia-Dugand S., O. Hjelm, L. Baas, and R.A. Ríos (2013). Lessons from the spread of Bus Rapid Transit in Latin America. *Journal of Cleaner Production* **50**, 82–90. doi: 10.1016/j.jclepro.2012.11.028, ISSN: 0959-6526.

Melosi M.V. (2000). *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present*. Johns Hopkins University Press, Baltimore, 578 pp. ISBN: 0801861527, 9780801861529.

Mickley L.J., D.J. Jacob, B.D. Field, and D. Rind (2004). Effects of future climate change on regional air pollution episodes in the United States. *Geophysical Research Letters* **31**, 1–4. doi: 10.1029/2004GL021216, ISSN: 1944-8007.

Mieszkowski P., and E.S. Mills (1993). The causes of metropolitan suburbanization. *The Journal of Economic Perspectives* **7**, 135–147. Available at: http://www.jstor.org/stable/10.2307/2138447.

Millard-Ball A. (2012a). Do city climate plans reduce emissions? *Journal of Urban Economics* **71**, 289–311. doi: 10.1016/j.jue.2011.12.004, ISSN: 00941190.

Millard-Ball A. (2012b). The Limits to Planning: Causal Impacts of City Climate Action Plans. *Journal of Planning Education and Research* **33**, 5–19. doi: 10.1177/0739456X12449742, ISSN: 0739-456X, 1552–6577.

Miller D. (1998). *Material Cultures: Why Some Things Matter*. University of Chicago Press, Chicago, US, 243 pp. Available at: http://www.press.uchicago.edu/ucp/books/book/chicago/M/bo3631823.html.

Milner J., M. Davies, and P. Wilkinson (2012). Urban energy, carbon management (low carbon cities) and co-benefits for human health. *Current Opinion in Environmental Sustainability* **4**, 398–404. doi: 10.1016/j.cosust.2012.09.011, ISSN: 18773435.

Minx J.C., G. Baiocchi, G.P. Peters, C.L. Weber, D. Guan, and K. Hubacek (2011). A "Carbonizing Dragon": China's Fast Growing CO_2 Emissions Revisited. *Environmental Science and Technology* **45**, 9144–9153. doi: 10.1021/es201497m, ISSN: 0013-936X.

Minx J., G. Baiocchi, T. Wiedmann, J. Barrett, F. Creutzig, K. Feng, M. Förster, P.-P. Pichler, H. Weisz, and K. Hubacek (2013). Carbon footprints of cities and other human settlements in the UK. *Environmental Research Letters* **8**, 035039. doi: 10.1088/1748-9326/8/3/035039, ISSN: 1748-9326.

Mogridge M.J.H. (1985). Transport, Land Use and Energy Interaction. *Urban Studies* **22**, 481–492.

Molina M.J., and L.T. Molina (2004). Megacities and Atmospheric Pollution. *Journal of the Air & Waste Management Association* **54**, 644–680. doi: 10.1080/10473289.2004.10470936, ISSN: 1096-2247.

Molloy R., and H. Shan (2013). The Effect of Gasoline Prices on Household Location. *Review of Economics and Statistics* **95**, 1212–1221. doi: 10.1162/REST_a_00331, ISSN: 0034-6535.

Montgomery M.R. (2008). The Urban Transformation of the Developing World. *Science* **319**, 761–764. doi: 10.1126/science.1153012.

Moore T., P. Thorsnes, B. Appleyard, and American Planning Association (2007). *The Transportation/land Use Connection*. American Planning Association, Planning Advisory Service, Chicago, 409 pp. ISBN: 9781932364422 1932364420.

Morello-Frosch R., M. Zuk, M. Jerrett, B. Shamasunder, and A.D. Kyle (2011). Understanding the cumulative impacts of inequalities in environmental health: implications for policy. *Health Affairs (Project Hope)* **30**, 879–887. doi: 10.1377/hlthaff.2011.0153, ISSN: 1544-5208.

Morris A.E.J. (1994). *A History of Urban Form: Before the Industrial Revolution*. Longman Scientific & Technical, Harlow, Essex, UK, 444 pp. ISBN: 9780582301542.

Moss T. (2003). Utilities, land-use change, and urban development: brownfield sites as "cold-spots" of infrastructure networks in Berlin. *Environment and Planning A* **35**, 511 – 529. doi: 10.1068/a3548.

Mraihi R., K. ben Abdallah, and M. Abid (2013). Road transport-related energy consumption: Analysis of driving factors in Tunisia. *Energy Policy* **62**, 247–253. doi: 10.1016/j.enpol.2013.07.007, ISSN: 03014215.

Muller P.O. (2004). Transportation and Urban Form—Stages in the Spatial Evolution of the American Metropolis. In: *The Geography of Urban Transportation*. S. Hanson, G. Guiliano, (eds.), Guilford Publications, New York, pp. 444. Available at: http://trid.trb.org/view.aspx?id=756060.

Müller D.B., G. Liu, A.N. Løvik, R. Modaresi, S. Pauliuk, F.S. Steinhoff, and H. Brattebø (2013). Carbon Emissions of Infrastructure Development. *Environmental Science & Technology* **47**, 11739-11746. doi: 10.1021/es402618m, ISSN: 0013-936X.

Mwampamba T.H. (2007). Has the woodfuel crisis returned? Urban charcoal consumption in Tanzania and its implications to present and future forest availability. *Energy Policy* **35**, 4221–4234. doi: 10.1016/j.enpol.2007.02.010, ISSN: 0301-4215.

Myors P., R. O'Leary, and R. Helstroom (2005). Multi-Unit Residential Buildings Energy and Peak Demand Study. *Energy News* **23**, 113–116. Available at: http://www.aie.org.au/Content/NavigationMenu/Publications/Energy_News_Archive.htm.

Næss P. (2005). Residential location affects travel behavior—but how and why? The case of Copenhagen metropolitan area. *Progress in Planning* **63**, 167–257. doi: 10.1016/j.progress.2004.07.004, ISSN: 03059006.

Næss P. (2006). Accessibility, Activity Participation and Location of Activities: Exploring the Links between Residential Location and Travel Behaviour. *Urban Studies* **43**, 627–652. doi: 10.1080/00420980500534677, ISSN: 0042-0980, 1360–063X.

Nasar J.L. (2003). Does Neotraditional Development Build Community? *Journal of Planning Education and Research* **23**, 58–68. doi: 10.1177/0739456X03256224, ISSN: 0739456X, 00000000.

National Research Council (2003). *Cities Transformed: Demographic Change and Its Implications in the Developing World* (M.R. Montgomery, R. Stren, B. Cohen, and H.E. Reed, Eds.). National Academies Press, Washington, D.C., 529 pp. ISBN: 9780309088626.

National Research Council (2009a). *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use and CO_2 Emissions*. The National Academies Press, Washington, D.C., 257 pp. Available at: http://www.nap.edu/catalog.php?record_id=12747.

National Research Council (2009b). Impacts of Land Use Patterns on Vehicle Miles Traveled. In: *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use and CO_2 Emissions*. The National Academies Press, Washington, D.C., pp. 50–105. ISBN: 9780309142557.

Ndrepepa A., and D. Twardella (2011). Relationship between noise annoyance from road traffic noise and cardiovascular diseases: A meta-analysis. *Noise and Health* **13**, 251–259. doi: 10.4103/1463-1741.80163, ISSN: 1463-1741.

Needham B. (2000). Land taxation, development charges, and the effects on land-use. *Journal of Property Research* **17**, 241–257. Routledge, doi: 10.1080/09599910050120000, ISSN: 0959-9916.

Nelson A.C. (1992). Preserving Prime Farmland in the Face of Urbanization: Lessons from Oregon. *Journal of the American Planning Association* **58**, 467–488. doi: 10.1080/01944369208975830, ISSN: 0194-4363.

Nelson A.C., R.J. Burby, E. Feser, C.J. Dawkins, E.E. Malizia, and R. Quercia (2004). Urban containment and central-city revitalization. *Journal of the American Planning Association* **70**, 411–425. Available at: http://www.tandfonline.com/doi/abs/10.1080/01944360408976391.

Nelson A.C., and J.B. Duncan (1995). *Growth Management Principles and Practices*. APA Planners Press, Chicago, 172 pp. ISBN: 9780918286925.

Nelson A.C., and T. Moore (1993). Assessing urban growth management: The case of Portland, Oregon, the USA's largest urban growth boundary. *Land Use Policy* **10**, 293–302. Available at: http://www.sciencedirect.com/science/article/pii/026483779390039D.

Nelson E., H. Sander, P. Hawthorne, M. Conte, D. Ennaanay, S. Wolny, S. Manson, and S. Polasky (2010). Projecting global land-use change and its effect on ecosystem service provision and biodiversity with simple models. *PLOS ONE* **5**, doi: 10.1371/journal.pone.0014327.

Nemet G.F., T. Holloway, and P. Meier (2010). Implications of incorporating air-quality co-benefits into climate change policymaking. *Environmental Research Letters* **5**, 014007. doi: 10.1088/1748-9326/5/1/014007, ISSN: 1748-9326.

Newman P., and J. Kenworthy (1999). *Sustainability and Cities: Overcoming Automobile Dependence*. Island Press, Washington, D.C., 468 pp. ISBN: 9781559636605.

Noland R.B. (2001). Relationships between highway capacity and induced vehicle travel. *Transportation Research Part A: Policy and Practice* **35**, 47–72. Available at: http://www.sciencedirect.com/science/article/pii/S0965856499000476.

Noland R.B., and L.L. Lem (2002). A review of the evidence for induced travel and changes in transportation and environmental policy in the US and the UK. *Transportation Research Part D: Transport and Environment* **7**, 1–26. Available at: http://www.sciencedirect.com/science/article/pii/S1361920901000098.

Norris D.F. (2001). Whither Metropolitan Governance? *Urban Affairs Review* **36**, 532–550. doi: 10.1177/10780870122184984, ISSN: 1078-0874, 1552–8332.

Nowak D.J., and D.E. Crane (2002). Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution* **116**, 381–389. doi: 10.1016/S0269-7491(01)00214-7, ISSN: 0269-7491.

Nuissl H., and C. Schroeter-Schlaack (2009). On the economic approach to the containment of land consumption. *Environmental Science & Policy* **12**, 270–280. doi: 10.1016/j.envsci.2009.01.008, ISSN: 14629011.

O'Neill B.C., M. Dalton, R. Fuchs, L. Jiang, S. Pachauri, and K. Zigova (2010). Global demographic trends and future carbon emissions. *Proceedings of the National Academy of Sciences* **107**, 17521–17526. doi: 10.1073/pnas.1004581107, ISSN: 0027-8424, 1091–6490.

O'Neill M.S., and K.L. Ebi (2009). Temperature extremes and health: impacts of climate variability and change in the United States. *Journal of Occupational and Environmental Medicine* **51**, 13–25. doi: 10.1097/JOM.0b013e318173e122.

O'Neill B.C., X. Ren, L. Jiang, and M. Dalton (2012). The effect of urbanization on energy use in India and China in the iPETS model. *Energy Economics* **34**, S339–S345. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84870500779&partnerID=40&md5=2246a009568f1dca91083df6a71fdfd9.

Oates W.E., and R.M. Schwab (1997). The impact of urban land taxation: the Pittsburgh experience. *National Tax Journal* **50**, 1–21.

Oatley N. (1995). Urban Regeneration. *Planning Practice and Research* **10**, 261–270. doi: 10.1080/02697459509696277, ISSN: 0269-7459, 1360–0583.

OECD (2006a). *OECD Territorial Reviews: Competitive Cities in the Global Economy*. Organisation for Economic Co-Operation and Development, Paris, France, 446 pp. Available at: http://www.oecd.org/gov/regional-policy/oecdterritorialreviewscompetitivecitiesintheglobaleconomy.htm.

OECD (2006b). *Infrastructure to 2030: Telecom, Land Transport, Water and Electricity (Volume 1)*. Organisation for Economic Co-Operation and Development (OECD), France, 355 pp. ISBN: 9264023984.

OECD (2007). *Infrastructure to 2030: Mapping Policy for Electricity, Water and Transport (Volume 2)*. Organisation for Economic Co-Operation and Development (OECD), France, 505 pp.

OECD (2010a). *Eco-Innovation in Industry: Enabling Green Growth*. Organisation for Economic Co-operation and Development, Paris, 276 pp. Available at: http://www.oecd.org/sti/ind/eco-innovationinindustryenablinggreengrowth.htm.

OECD (2010b). *Cities and Climate Change*. Organisation for Economic Co-operation and Development Publishing, Paris, France, 276 pp. ISBN: 9789264091375.

OECD (2010c). *OECD Territorial Reviews: Guangdong, China 2010*. Organisation for Economic Co-operation and Development Publishing, 311 pp. ISBN: 9789264090088.

OECD (2010d). Financial Instruments and Funding New Expenditure Needs. In: *Cities and Climate Change*. Organisation for Economic Co-operation and Development, pp. 227–249. Available at: http://www.oecd-ilibrary.org/content/chapter/9789264091375-14-en.

Orfield M. (2002). *American Metropolitics: The New Suburban Reality*. Brookings Institution Press, Washington, D.C., 333 pp. ISBN: 0815705441.

Owen N., E. Cerin, E. Leslie, L. duToit, N. Coffee, L.D. Frank, A.E. Bauman, G. Hugo, B.E. Saelens, and J.F. Sallis (2007). Neighborhood Walkability and the Walking Behavior of Australian Adults. *American Journal of Preventive Medicine* **33**, 387–395. doi: 10.1016/j.amepre.2007.07.025, ISSN: 0749-3797.

Pachauri S., A. Brew-Hammond, D.F. Barnes, D.H. Bouille, S. Gitonga, V. Modi, G. Prasad, A. Rath, and H. Zerriffi (2012). Chapter 19—Energy Access for Development. In: *Global Energy Assessment—Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 1401–1458. ISBN: 9781 10700 5198 hardback 9780 52118 2935 paperback.

Pachauri S., and L. Jiang (2008). The household energy transition in India and China. *Energy Policy* **36**, 4022–4035. doi: 10.1016/j.enpol.2008.06.016, ISSN: 0301-4215.

Paloheimo E., and O. Salmi (2013). Evaluating the carbon emissions of the low carbon city: A novel approach for consumer based allocation. *Cities* **30**, 233–239. doi: 10.1016/j.cities.2012.04.003, ISSN: 0264-2751.

Parikh J., and V. Shukla (1995). Urbanization, energy use and greenhouse effects in economic development: Results from a cross-national study of developing countries. *Global Environmental Change* **5**, 87–103. doi: 10.1016/0959-3780(95)00015-G, ISSN: 0959-3780.

Parolek D.G., K. Parolek, and P.C. Crawford (2008). *Form-Based Codes. A Guide for Planners, Urban Designers, Municipalities, and Developers*. John Wiley & Sons, Hoboken, NJ, 332 pp.

Parshall L., K. Gurney, S.A. Hammer, D. Mendoza, Y. Zhou, and S. Geethakumar (2010). Modeling energy consumption and CO_2 emissions at the urban scale: Methodological challenges and insights from the United States. *Energy Policy* **38**, 4765–4782. doi: 10.1016/j.enpol.2009.07.006, ISSN: 0301-4215.

Pataki D.E., P.C. Emmi, C.B. Forster, J.I. Mills, E.R. Pardyjak, T.R. Peterson, J.D. Thompson, and E. Dudley-Murphy (2009). An integrated approach to improving fossil fuel emissions scenarios with urban ecosystem studies. *Ecological Complexity* **6**, 1–14. doi: 10.1016/j.ecocom.2008.09.003, ISSN: 1476-945X.

Pendall R. (1999). Do land-use controls cause sprawl? *Environment & Planning B: Planning & Design* **26**, 555–571. Available at: http://www.envplan.com/abstract.cgi?id=b260555.

Pendall R., J. Martin, and W. Fulton (2002). Holding the Line: Urban Containment in the United States. Brookings Institution Center on Urban and Metropolitan Policy. Available at: http://www.brookings.edu/~/media/research/files/reports/2002/8/metropolitanpolicy%20pendall/pendallfultoncontainment.

Pendall R., B. Theodos, and K. Franks (2012). *The Built Environment and Household Vulnerability in a Regional Context*. Urban Institute, Washington, D.C., 10 pp. Available at: http://www.urban.org/UploadedPDF/412609-The-Built-Environment-and-Household-Vulnerability-in-a-Regional-Context.pdf?RSSFeed=UI_CitiesandNeighborhoods.xml.

Perkins A., S. Hamnett, S. Pullen, R. Zito, and D. Trebilcock (2009). Transport, Housing and Urban Form: The Life Cycle Energy Consumption and Emissions of City Centre Apartments Compared with Suburban Dwellings. *Urban Policy and Research* **27**, 377–396. doi: 10.1080/08111140903308859, ISSN: 0811-1146.

Permana A.S., R. Perera, and S. Kumar (2008). Understanding energy consumption pattern of households in different urban development forms: A comparative study in Bandung City, Indonesia. *Energy Policy* **36**, 4287–4297.

Peters G.P., C.L. Weber, D. Guan, and K. Hubacek (2007). China's Growing CO_2 Emissions—A Race between Increasing Consumption and Efficiency Gains. *Environmental Science & Technology* **41**, 5939–5944. doi: 10.1021/es070108f, ISSN: 0013-936X.

Peterson G.E. (2009). *Unlocking Land Values to Finance Urban Infrastructure*. World Bank, Washington, D.C., 128 pp. ISBN: 9780821377093.

Petsch S., S. Guhathakurta, L. Heischbourg, K. Müller, and H. Hagen (2011). Modeling, Monitoring, and Visualizing Carbon Footprints at the Urban Neighborhood Scale. *Journal of Urban Technology* **18**, 81–96. doi: 10.1080/10630732.2011.648436, ISSN: 1063-0732.

Peyroux E. (2012). Legitimating Business Improvement Districts in Johannesburg: a discursive perspective on urban regeneration and policy transfer. *European Urban and Regional Studies* **19**, 181–194. doi: 10.1177/0969776411420034, ISSN: 0969-7764, 1461–7145.

Picken D.H., and B.D. Ilozor (2003). Height and construction costs of buildings in Hong Kong. *Construction Management and Economics* **21**, 107–111.

Pickrell D., and P. Schimek (1999). Growth in motor vehicle ownership and use: evidence from the nationwide personal transportation survey. *Journal of Transportation and Statistics* **2**, 1–18. ISSN: 1094-8848.

Pirie G. (2011). *Sustainable Urban Mobility in "Anglophone" Sub-Saharan Africa*. UN-Habitat, Nairobi, 53 pp. Available at: http://www.unhabitat.org/downloads/docs/GRHS.2013.Regional.Anglophone.Africa.pdf.

Pitt D. (2010). The impact of internal and external characteristics on the adoption of climate mitigation policies by US municipalities. *Environment and Planning C-Government and Policy* **28**, 851–871. doi: 10.1068/c09175, ISSN: 0263-774X.

Plassmann F., and T.N. Tideman (2000). A Markov Chain Monte Carlo Analysis of the Effect of Two-Rate Property Taxes on Construction. *Journal of Urban Economics* **47**, 216–247. doi: 10.1006/juec.1999.2140, ISSN: 00941190.

Pogodzinski J.M., and T.R. Sass (1994). The Theory and Estimation of Endogenous Zoning. *Regional Science and Urban Economics* **24**, 601–630. Available at: http://www.elsevier.com/wps/find/journaldescription.cws_home/505570/description#description http://search.ebscohost.com/login.aspx?direct=true&db=ecn&AN=0346226&site=ehost-live.

Porter D.R. (1997). *Managing Growth in America's Communities*. Island Press, Washington, D.C., 311 pp. ISBN: 9781559634427.

Potter S. (1984). *Transport and New Towns: The Transport Assumptions Underlying the Design of Britain's New Towns, 1946–1976*. Open University, New Towns Study Unit, 9 pp.

Puga D. (2010). The magnitude and causes of agglomeration economies. *Journal of Regional Science* **50**, 203–219. doi: 10.1111/j.1467-9787.2009.00657.x, ISSN: 00224146, 14679787.

Puppim de Oliveira J.A. (2009). The implementation of climate change related policies at the subnational level: An analysis of three countries. *Habitat International* **33**, 253–259. doi: 10.1016/j.habitatint.2008.10.006, ISSN: 0197-3975.

Puppim de Oliveira J.A., C.N.H. Doll, T.A. Kurniawan, Y. Geng, M. Kapshe, and D. Huisingh (2013). Promoting win–win situations in climate change mitigation, local environmental quality and development in Asian cities through co-benefits. *Journal of Cleaner Production* **58**, 1–6. doi: 10.1016/j.jclepro.2013.08.011, ISSN: 0959-6526.

Pushkar A.O., B.J. Hollingworth, and E.J. Miller (2000). A multivariate regression model for estimating greenhouse gas emissions from alternative neighborhood designs. In: *79th annual meeting of the Transportation Research Board, Washington, DC*. Available at: http://www.civ.utoronto.ca/sect/traeng/ilute/downloads/conference_papers/pushkar-etal_trb-00.pdf.

PwC and Partnership for New York City (2012). *Cities of Opportunity 2012*. PriceWaterhouseCoopers LLP, Delaware, USA, 96 pp. Available at: http://www.pwc.es/es_ES/es/publicaciones/sector-publico/assets/cities-of-opportunity-2012.pdf.

Quigley J.M., and S. Raphael (2005). Regulation and the High Cost of Housing in California. *The American Economic Review* **95**, 323–328. ISSN: 0002-8282.

Raciti S.M., L.R. Hutyra, P. Rao, and A.C. Finzi (2012). Inconsistent definitions of "urban" result in different conclusions about the size of urban carbon and nitrogen stocks. *Ecological Applications* **22**, 1015–1035. doi: 10.1890/11-1250.1, ISSN: 1051-0761.

Ramaswami A. (2013). Understanding Infrastructure Impacts on Urban Greenhouse Gas Emissions and Key Mitigation Strategies. In: *Infrastructure and Land Polices*. Lincoln Institute of Land Policy, Cambridge, MA, pp. 296–317. ISBN: 9781558442511.

Ramaswami A., M. Bernard, A. Chavez, T. Hillman, M. Whitaker, G. Thomas, and M. Marshall (2012a). Quantifying Carbon Mitigation Wedges in U.S. Cities: Near-Term Strategy Analysis and Critical Review. *Environmental Science & Technology* **46**, 3629–3642. doi: 10.1021/es203503a, ISSN: 0013-936X.

Ramaswami A., A. Chavez, and M. Chertow (2012b). Carbon Footprinting of Cities and Implications for Analysis of Urban Material and Energy Flows. *Journal of Industrial Ecology* **16**, 783–785. doi: 10.1111/j.1530-9290.2012.00569.x, ISSN: 1530-9290.

Ramaswami A., A. Chavez, J. Ewing-Thiel, and K.E. Reeve (2011). Two approaches to greenhouse gas emissions foot-printing at the city scale. *Environmental Science & Technology* **45**, 4205–4206. doi: 10.1021/es201166n, ISSN: 1520-5851.

Ramaswami A., T. Hillman, B. Janson, M. Reiner, and G. Thomas (2008). A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories. *Environmental Science & Technology* **42**, 6455–6461. doi: 10.1021/es702992q, ISSN: 0013-936X.

Rao S., S. Pachauri, F. Dentener, P. Kinney, Z. Klimont, K. Riahi, and W. Schoepp (2013). Better air for better health: Forging synergies in policies for energy access, climate change and air pollution. *Global Environmental Change* **23**, 1122–1130. doi: 10.1016/j.gloenvcha.2013.05.003, ISSN: 0959-3780.

Rashed T., J.R. Weeks, D. Roberts, J. Rogan, and R. Powell (2003). Measuring the physical composition of urban morphology using multiple endmember spectral mixture models. *Photogrammetric Engineering and Remote Sensing* **69**, 1011–1020. ISSN: 0099-1112.

Ratti C., N. Baker, and K. Steemers (2005). Energy consumption and urban texture. *Energy and Buildings* **37**, 762–776.

Raupach M.R., P.J. Rayner, and M. Paget (2010). Regional variations in spatial structure of nightlights, population density and fossil-fuel CO_2 emissions. *Energy Policy* **38**, 4756–4764. doi: 10.1016/j.enpol.2009.08.021, ISSN: 0301-4215.

Reilly M.K., M.P. O'Mara, and K.C. Seto (2009). From Bangalore to the Bay Area: Comparing transportation and activity accessibility as drivers of urban growth. *Landscape and Urban Planning* **92**, 24–33. doi: 10.1016/j.landurbplan.2009.02.001, ISSN: 01692046.

Renforth P., D.A.C. Manning, and E. Lopez-Capel (2009). Carbonate precipitation in artificial soils as a sink for atmospheric carbon dioxide. *Applied Geochemistry* **24**, 1757–1764. doi: 10.1016/j.apgeochem.2009.05.005, ISSN: 0883-2927.

Richardson G.R.A., and J. Otero (2012). *Land Use Planning Tools for Local Adaptation to Climate Change*. Government of Canada, Ottawa, 23 pp. Available at: http://publications.gc.ca/collections/collection_2013/rncan-nrcan/M4-106-2012-eng.pdf.

Rickwood P., G. Glazebrook, and G. Searle (2008). Urban Structure and Energy—A Review. *Urban Policy and Research* **26**, 57–81. doi: 10.1080/08111140701629886.

Roakes S.L. (1996). Reconsidering land value taxation. *Land Use Policy* **13**, 261–272. doi: 10.1016/0264-8377(96)84556-X, ISSN: 02648377.

Rodier C.J. (2009). *A Review of the International Modeling Literature: Transit, Land Use, and Auto Pricing Strategies to Reduce Vehicle Miles Traveled and Greenhouse Gas Emissions*. Institute of Transportation Studies, University of California, Davis, Davis, California, 32 pp. Available at: http://www.its.ucdavis.edu/wp-content/themes/ucdavis/pubs/download_pdf.php?id=1350.

Rodrik D., A. Subramanian, and F. Trebbi (2004). Institutions Rule: The Primacy of Institutions Over Geography and Integration in Economic Development. *Journal of Economic Growth* **9**, 131–165. doi: 10.1023/B:JOEG.0000031425.72248.85, ISSN: 1381-4338, 1573-7020.

Rogers R.G. (1999). *Towards an Urban Renaissance*. Spon Press, London, 328 pp. ISBN: 185112165X.

Rolon A. (2008). Evaluation of Value Capture Mechanisms from Linkage Capture to Special Assessment Districts. *Transportation Research Record: Journal of the Transportation Research Board* **2079**, 127–135. doi: 10.3141/2079-16.

Romanos M.C. (1978). Energy-price effects on metropolitan spatial structure and form. *Environment & Planning A* **10**, 93–104. Available at: http://envplan.com/abstract.cgi?id=a100093.

Romero Lankao P. (2007). How do Local Governments in Mexico City Manage Global Warming? *Local Environment* **12**, 519–535. doi: 10.1080/13549830701656887, ISSN: 1354-9839.

Rosenfeld A.H., H. Akbari, J.J. Romm, and M. Pomerantz (1998). Cool communities: strategies for heat island mitigation and smog reduction. *Energy and Buildings* **28**, 51–62. doi: 10.1016/S0378-7788(97)00063-7, ISSN: 0378-7788.

Rosenthal S.S., and W.C. Strange (2004). Evidence on the nature and sources of agglomeration economies. In: *Handbook of Regional and Urban Economics* **4**, 2119–2171 J.V. Henderson, J.-F. Thisse, (eds.), Elsevier, Amsterdam ; New York: North-Holland ; New York, N.Y., U.S.A. ISBN: 9780444509673.

Rosenzweig C., W.D. Solecki, S.A. Hammer, and S. Mehrotra (2011). *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*. Cambridge University Press, Cambridge, UK, 312 pp.

Ru G., C. Xiaojing, Y. Xinyu, L. Yankuan, J. Dahe, and L. Fengting (2010). The strategy of energy-related carbon emission reduction in Shanghai. *Energy Policy* **38**, 633–638. doi: 10.1016/j.enpol.2009.06.074, ISSN: 0301-4215.

Rubin J.I., and J.J. Seneca (1991). Density bonuses, exactions, and the supply of affordable housing. *Journal of Urban Economics* **30**, 208–223. ISSN: 00941190.

Rusk D. (1995). *Cities without Suburbs*. Woodrow Wilson Center Press, Princeton, NJ, 180 pp. ISBN: 9780943875743.

Rutland T., and A. Aylett (2008). The work of policy: Actor networks, governmentality, and local action on climate change in Portland, Oregon. *Environment and Planning D: Society and Space* **26**, 627–646. doi: 10.1068/d6907, ISSN: 02637758.

Rydin Y., A. Bleahu, M. Davies, J.D. Dávila, S. Friel, G. De Grandis, N. Groce, P.C. Hallal, I. Hamilton, P. Howden-Chapman, K.-M. Lai, C. Lim, J. Martins, D. Osrin, I. Ridley, I. Scott, M. Taylor, P. Wilkinson, and J. Wilson (2012). Shaping cities for health: complexity and the planning of urban environments in the 21st century. *The Lancet* **379**, 2079–2108. doi: 10.1016/S0140-6736(12)60435-8, ISSN: 01406736.

Saelens B.E., J.F. Sallis, and L.D. Frank (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine* **25**, 80–91. doi: 10.1207/S15324796ABM2502_03, ISSN: 0883-6612, 1532–4796.

Sælensminde K. (2004). Cost–benefit analyses of walking and cycling track networks taking into account insecurity, health effects and external costs of motorized traffic. *Transportation Research Part A: Policy and Practice* **38**, 593–606. doi: 10.1016/j.tra.2004.04.003, ISSN: 0965-8564.

Sagalyn L.B. (2007). Public/Private Development : Lessons from History, Research, and Practice. *Journal of the American Planning Association* **73**, 7–22. doi: 10.1080/01944360708976133, ISSN: 0194-4363.

Sahakian M.D., and J.K. Steinberger (2011). Energy Reduction Through a Deeper Understanding of Household Consumption. *Journal of Industrial Ecology* **15**, 31–48. doi: 10.1111/j.1530-9290.2010.00305.x, ISSN: 1530-9290.

Salat S. (2009). Energy loads, CO_2 emissions and building stocks: morphologies, typologies, energy systems and behaviour. *Building Research & Information* **37**, 598–609. doi: 10.1080/09613210903162126, ISSN: 0961-3218, 1466–4321.

Salat S. (2011). *Cities and Forms:* On Sustainable Urbanism. Hermann, 544 pp. ISBN: 2705681116.

Sallis J.F., B.E. Saelens, L.D. Frank, T.L. Conway, D.J. Slymen, K.L. Cain, J.E. Chapman, and J. Kerr (2009). Neighborhood built environment and income: Examining multiple health outcomes. *Social Science & Medicine* **68**, 1285–1293. doi: 10.1016/j.socscimed.2009.01.017, ISSN: 0277-9536.

Salomon I., and P.L. Mokhtarian (1998). What happens when mobility-inclined market segments face accessibility-enhancing policies? *Transportation Research Part D: Transport and Environment* **3**, 129–140. doi: 10.1016/S1361-9209(97)00038-2, ISSN: 1361-9209.

Salon D., M.G. Boarnet, S. Handy, S. Spears, and G. Tal (2012). How do local actions affect VMT? A critical review of the empirical evidence. *Transportation Research Part D: Transport and Environment* **17**, 495–508. doi: 10.1016/j.trd.2012.05.006, ISSN: 1361-9209.

Salon D., D. Sperling, A. Meier, S. Murphy, R. Gorham, and J. Barrett (2010). City carbon budgets: A proposal to align incentives for climate-friendly communities. *Energy Policy* **38**, 2032–2041.

Sammer G. (2013). Transport Systems. In: *Energizing Sustainable Cities: Assessing Urban Energy*. A. Grubler, D. Fisk, (eds.), Routledge, Abingdon, Oxon, UK, pp. 135–154. ISBN: 9781849714396.

Sandroni P. (2010). A New Financial Instrument of Value Capture in São Paulo. In: *Municipal Revenues and Land Policies*. G.K. Ingram, Y.-H. Hong, (eds.), Lincoln Institute of Land Policy., Cambridge, MA, pp. 218–236.

Santero N.J., and A. Horvath (2009). Global warming potential of pavements. *Environmental Research Letters* **4**, 034011. doi: 10.1088/1748-9326/4/3/034011, ISSN: 1748-9326.

Santos E. (2011). *Curitiba, Brazil: Pioneering in Developing Bus Rapid Transit and Urban Planning Solutions*. Lap Lambert Academic Publishing, Saarbrücken, Deutschland, 221 pp. ISBN: 3844332995 9783844332995.

Satterthwaite D. (2007). *The Transition to a Predominantly Urban World and Its Underpinnings*. IIED, London, 99 pp. Available at: http://pubs.iied.org/10550IIED.html?k=Urban-change&s=HSWP&b=d.

Satterthwaite D. (2009). The implications of population growth and urbanization for climate change. *Environment and Urbanization* **21**, 545–567. doi: 10.1177/0956247809344361, ISSN: 0956-2478.

Schäfer A. (2005). Structural change in energy use. *Energy Policy* **33**, 429–437. doi: 10.1016/j.enpol.2003.09.002, ISSN: 0301-4215.

Schimek P. (1996). Household Motor Vehicle Ownership and Use: How Much Does Residential Density Matter? *Transportation Research Record: Journal of the Transportation Research Board* **1552**, 120–125. doi: 10.3141/1552-17.

Schneider K. (2003). *The Paris-Lexington Road: Community-Based Planning And Context Sensitive Highway Design*. Island Press, Washington, D.C., 106 pp. ISBN: 9781597263009.

Schneider A., M.A. Friedl, and D. Potere (2009). A new map of global urban extent from MODIS satellite data. *Environmental Research Letters* **4**, 044003. doi: 10.1088/1748-9326/4/4/044003, ISSN: 1748-9326.

Schulz N.B. (2010). Delving into the carbon footprints of Singapore—comparing direct and indirect greenhouse gas emissions of a small and open economic system. *Energy Policy* **38**, 4848–4855. doi: 10.1016/j.enpol.2009.08.066, ISSN: 0301-4215.

Scott K.I., J.R. Simpson, and E.G. McPherson (1999). Effects of tree cover on parking lot microclimate and vehicle emissions. *Journal of Arboriculture* **25**, 129–142. Available at: http://www.fs.fed.us/psw/programs/uesd/uep/products/11/psw_cufr68_EffectsTreeCoverOnEmissions.pdf.

Seltzer E., and A. Carbonell (2011). *Regional Planning in America: Practice and Prospect*. Lincoln Institute of Land Policy, Cambridge, MA, 288 pp. ISBN: 9781558442153.

Seto K.C., M. Fragkias, B. Güneralp, and M.K. Reilly (2011). A Meta-Analysis of Global Urban Land Expansion. *PLOS ONE* **6**, e23777. doi: 10.1371/journal.pone.0023777.

Seto K.C., B. Güneralp, and L.R. Hutyra (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences* **109**, 16083–16088. doi: 10.1073/pnas.1211658109, ISSN: 0027-8424, 1091–6490.

Seto K.C., R. Sánchez-Rodríguez, and M. Fragkias (2010). The New Geography of Contemporary Urbanization and the Environment. *Annual Review of Environment and Resources* **35**, 167–194. doi: 10.1146/annurev-environ-100809-125336.

Shove E. (2003). Users, technologies and expectations of comfort, cleanliness and convenience. *Innovation* **16**, 193–206. doi: 10.1080/13511610304521, ISSN: 13511610.

Shove E. (2004). *Comfort, Cleanliness and Convenience: The Social Organization of Normality*. Berg Publishers, New York, USA, 221 pp. ISBN: 1859736300.

Shrestha R.M., and S. Rajbhandari (2010). Energy and environmental implications of carbon emission reduction targets: Case of Kathmandu Valley, Nepal. *Energy Policy* **38**, 4818–4827. doi: 10.1016/j.enpol.2009.11.088, ISSN: 0301-4215.

Sippel M. (2011). Urban GHG inventories, target setting and mitigation achievements: how German cities fail to outperform their country. *Greenhouse Gas Measurement and Management* **1**, 55–63. doi: 10.3763/ghgmm.2010.0001, ISSN: 2043-0779.

Sivam A. (2002). Constraints affecting the efficiency of the urban residential land market in developing countries: a case study of India. *Habitat International* **26**, 523–537.

Skaburskis A. (2003). Pricing city form: development cost charges and simulated markets. *Planning Practice and Research* **18**, 197–211. Routledge, doi: 10.1080/0269745032000168250, ISSN: 0269-7459.

Slabbert N. (2005). Telecommunities. *Urban Land* **64**, pp.86–92. Available at: http://www.virtualadjacency.com/wp-content/uploads/2008/01/9-uli-telecommunities-may2005.pdf.

Smith K.R., K. Balakrishnan, C. Butler, Z. Chafe, I. Fairlie, P. Kinney, T. Kjellstrom, D.L. Mauzerall, T. McKone, A. McMichael, M. Schneider, and P. Wilkinson (2012). Energy and Health. In: *Global Energy Assessment: Toward a Sustainable Future*. Cambridge University Press; International Institute for Applied Systems Analysis, Cambridge, UK and New York, NY, USA; Laxenburg, Austria, pp. 255–324. Available at: http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter4_health_lowres.pdf.

Smith J.J., and T.A. Gihring (2006). Financing Transit Systems Through Value Capture: An Annotated Bibliography. *The American Journal of Economics and Sociology* **65**, 751–786.

Smith C., and G. Levermore (2008). Designing urban spaces and buildings to improve sustainability and quality of life in a warmer world. *Energy Policy* **36**, 4558–4562. doi: 10.1016/j.enpol.2008.09.011, ISSN: 0301-4215.

Song Y., and Y. Zenou (2006). Property tax and urban sprawl: Theory and implications for US cities. *Journal of Urban Economics* **60**, 519–534. doi: 10.1016/j.jue.2006.05.001, ISSN: 00941190.

Sovacool B.K., and M.A. Brown (2010). Twelve metropolitan carbon footprints: A preliminary comparative global assessment. *Energy Policy* **38**, 4856–4869. doi: 10.1016/j.enpol.2009.10.001, ISSN: 0301-4215.

Speir C., and K. Stephenson (2002). Does Sprawl Cost Us All? Isolating the Effects of Housing Patterns on Public Water and Sewer Costs. *Journal of the American Planning Association* **68**, 56–70. doi: 10.1080/01944360208977191, ISSN: 0194-4363.

Sridhar K.S. (2007). Density gradients and their determinants: Evidence from India. *Regional Science and Urban Economics* **37**, 314–344. doi: 10.1016/j.regsciurbeco.2006.11.001, ISSN: 01660462.

Sridhar K.S. (2010). Impact of Land Use Regulations: Evidence from India's Cities. *Urban Studies* **47**, 1541–1569. doi: 10.1177/0042098009353813, ISSN: 0042-0980, 1360–063X.

Srinivasan S., and P. Rogers (2005). Travel behavior of low-income residents: studying two contrasting locations in the city of Chennai, India. *Journal of Transport Geography* **13**, 265–274. doi: 10.1016/j.jtrangeo.2004.07.008, ISSN: 0966-6923.

State of California (2008). Sustainable Communities and Climate Protection Act of 2008, Senate Bill No. 375. *Chapter 728*. Available at: http://www.leginfo.ca.gov/pub/07–08/bill/sen/sb_0351–0400/sb_375_bill_20080930_chaptered.pdf.

Steinberger J., and H. Weisz (2013). City walls and urban hinterlands: the importance of system boundaries. In: *Energizing Sustainable Cities: Assessing Urban Energy*. A. Grubler, D. Fisk, (eds.), Routledge, pp. 41–56. ISBN: 9781849714396.

Stone B., J. Vargo, and D. Habeeb (2012). Managing climate change in cities: Will climate action plans work? *Landscape and Urban Planning* **107**, 263–271.

Strohbach M.W., E. Arnold, and D. Haase (2012). The carbon footprint of urban green space—A life cycle approach. *Landscape and Urban Planning* **104**, 220–229. doi: 10.1016/j.landurbplan.2011.10.013, ISSN: 01692046.

Sugar L., C. Kennedy, and E. Leman (2012). Greenhouse Gas Emissions from Chinese Cities. *Journal of Industrial Ecology* **16**, 552–563. doi: 10.1111/j.1530-9290.2012.00481.x, ISSN: 1530-9290.

Sugiyama N., and T. Takeuchi (2008). Local Policies for Climate Change in Japan. *The Journal of Environment & Development* **17**, 424–441. doi: 10.1177/1070496508326128.

Sun X., C. Wilmot, and T. Kasturi (1998). Household Travel, Household Characteristics, and Land Use: An Empirical Study from the 1994 Portland Activity-Based Travel Survey. *Transportation Research Record* **1617**, 10–17. doi: 10.3141/1617-02, ISSN: 0361-1981.

Suzuki H., R. Cervero, and K. Iuchi (2013). *Transforming Cities with Transit: Transit and Land-Use Integration for Sustainable Urban Development*. World Bank, Washington, D.C., 205 pp. ISBN: 9780821397459, 0821397451, 9780821397503, 0821397508.

Synnefa A., T. Karlessi, N. Gaitani, M. Santamouris, D.N. Assimakopoulos, and C. Papakatsikas (2011). Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate. *Building and Environment* **46**, 38–44. doi: 10.1016/j.buildenv.2010.06.014, ISSN: 0360-1323.

Talen E. (2005). *New Urbanism and American Planning: The Conflict of Cultures*. Routledge, New York, US, 329 pp. ISBN: 9780203799482.

Talen E. (2012). *City Rules: How Regulations Affect Urban Form*. Island Press, Washington D.C., 236 pp.

Tang Z., Z. Wang, and T. Koperski (2011). Measuring local climate change response capacity and bridging gaps between local action plans and land use plans. *International Journal of Climate Change Strategies and Management* **3**, 74–100. doi: 10.1108/17568691111107952, ISSN: 17568692.

Tanguay G.A., and I. Gingras (2012). Gas price variations and urban sprawl: An empirical analysis of the twelve largest Canadian metropolitan areas. *Environment and Planning A* **44**, 1728–1743. doi: 10.1068/a44259, ISSN: 0308518X.

Tarr J.A. (1984). The Search for the Ultimate Sink: Urban Air, Land, and Water Pollution in Historical Perspective. *Records of the Columbia Historical Society* **51**, 1–29. doi: 10.2307/40067842, ISSN: 0897-9049.

Teriman S., T. Yigitcanlar, and S. Mayere (2010). Sustainable Urban Infrastructure Development in South East Asia: Evidence from Hong Kong, Kuala Lumpur and Singapore. In: *Sustainable Urban and Regional Infrastructure Development: Technologies, Applications and Management*. T. Yigitcanlar, (ed.), IGI Global, Hershey, PA, pp. 152–164. ISBN: 978-1-61520-775-6.

The Covenant of Mayors (2013). The Covenant of Mayors. Available at: http://www.covenantofmayors.eu/index_en.html.

Tisdale, H. (1942) The process of urbanization. *Social Forces* **20** (3), 311 pp

Townsend-Small A., and C.I. Czimczik (2010). Carbon sequestration and greenhouse gas emissions in urban turf. *Geophysical Research Letters* **37**, 5 PP. doi: 201010.1029/2009GL041675.

Trudeau D. (2013). A typology of New Urbanism neighborhoods. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability* **6**, 113–138. doi: 10.1080/17549175.2013.771695, ISSN: 1754-9175.

U.S. Department of Transportation (2009). *2009 National Household Travel Survey*. U.S. Department of Transportation, Washinton, D.C. Available at: http://nhts.gov/index.shtml.

U.S. EPA (2013). *Infrastructure Financing Options for Transit-Oriented Development*. Office of Sustainable Communities Smart Growth Program, Washington, D.C., 251 pp.

UN DESA (2010). *World Urbanization Prospects: The 2009 Revision*. United Nations, Department of Economic and Social Affairs, Population Division, New York.

UN DESA (2012). *World Urbanization Prospects: The 2011 Revision*. United Nations, Department of Economic and Social Affairs, Population Division, New York.

UN DESA (2013). Population Density and Urbanization. Available at: http://unstats.un.org/unsd/demographic/sconcerns/densurb/densurbmethods.htm.

UNEP, UN Habitat, and The World Bank (2010). International Standard for Determining Greenhouse Gas Emissions for Cities, version 2.1. United Nations Environment Programme. Available at: http://www.unep.org/urban_environment/PDFs/InternationalStd-GHG.pdf.

UN-Habitat (2008). *State of the World's Cities 2008/2009: Harmonious Cities*. UN-Habitat; Earthscan, London, 224 pp. ISBN: 9789211320107, 9211320100, 9789211320114, 9211320119, 9781844076963, 1844076962, 9781844076956, 1844076954.

UN-Habitat (2012). *State of the World's Cities 2012/2013*. Routledge, New York, 184 pp. ISBN: 978-0-415-83888-7.

UN-Habitat (2013). *Planning and Design for Sustainable Urban Mobility: Global Report on Human Settlements 2013*. Earthscan/UN HABITAT, Abingdon, Oxon. Available at: http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=3503.

United Nations (2011). National Accounts Main Aggregates Database. *National Accounts Main Aggregates Database (United Nations Statistics Division)*. Available at: https://unstats.un.org/unsd/snaama/Introduction.asp.

Unruh G.C. (2000). Understanding carbon lock-in. *Energy Policy* **28**, 817–830. doi: 10.1016/S0301-4215(00)00070-7, ISSN: 0301-4215.

Unruh G.C. (2002). Escaping carbon lock-in. *Energy Policy* **30**, 317–325. doi: 10.1016/S0301-4215(01)00098-2, ISSN: 0301-4215.

Unruh G.C., and J. Carrillo-Hermosilla (2006). Globalizing carbon lock-in. *Energy Policy* **34**, 1185–1197. doi: 10.1016/j.enpol.2004.10.013, ISSN: 0301-4215.

Urban LandMark (2012). *Improving Access to the City through Value Capture: An Overview of Capturing and Allocating Value Created through the Development of Transport Infrastructure in South Africa*. UK Department for International Development, London, 60 pp.

Vance C., and R. Hedel (2007). The impact of urban form on automobile travel: disentangling causation from correlation. *Transportation* **34**, 575–588. doi: 10.1007/s11116-007-9128-6, ISSN: 0049-4488, 1572–9435.

Vause J., L. Gao, L. Shi, and J. Zhao (2013). Production and consumption accounting of CO_2 emissions for Xiamen, China. *Energy Policy* **60**, 697–704. doi: 10.1016/j.enpol.2013.04.069, ISSN: 0301-4215.

Venkataraman C., A.D. Sagar, G. Habib, N. Lam, and K.R. Smith (2010). The Indian National Initiative for Advanced Biomass Cookstoves: The benefits of clean combustion. *Energy for Sustainable Development* **14**, 63–72. doi: 10.1016/j.esd.2010.04.005, ISSN: 0973-0826.

Vickrey W.S. (1969). Congestion theory and transport investment. *The American Economic Review* **59**, 251–260. Available at: http://www.jstor.org/stable/10.2307/1823678.

Vringer K., and K. Blok (1995). The direct and indirect energy requirements of households in the Netherlands. *Energy Policy* **23**, 893–910. doi: 10.1016/0301-4215(95)00072-Q, ISSN: 0301-4215.

Wachs M., and T.G. Kumagai (1973). Physical accessibility as a social indicator. *Socio-Economic Planning Sciences* **7**, 437–456. doi: 10.1016/0038-0121(73)90041-4, ISSN: 00380121.

Wang R. (2013). Adopting Local Climate Policies: What Have California Cities Done and Why? *Urban Affairs Review* **49**, 593–613. doi: 10.1177/1078087412469348, ISSN: 1078-0874.

Wang W., L. Ren, Q. Guo, and T. Chen (2012a). Predicating Energy Demand and Carbon Emissions of the Yellow River Delta High-efficiency Eco-economic Zone. *Energy Procedia* **14**, 229–234. doi: 10.1016/j.egypro.2011.12.922, ISSN: 1876-6102.

Wang R., and Q. Yuan (2013). Parking practices and policies under rapid motorization: The case of China. *Transport Policy* **30**, 109–116. doi: j.tranpol.2013.08.006.

Wang H., R. Zhang, M. Liu, and J. Bi (2012b). The carbon emissions of Chinese cities. *Atmospheric Chemistry and Physics* **12**, 6197–6206. doi: 10.5194/acp-12-6197-2012, ISSN: 1680-7324.

Wang Y., H. Zhao, L. Li, Z. Liu, and S. Liang (2013). Carbon dioxide emission drivers for a typical metropolis using input–output structural decomposition analysis. *Energy Policy* **58**, 312–318. doi: 10.1016/j.enpol.2013.03.022, ISSN: 03014215.

Weber M. (1966). *The City*. The Free Press, New York, 242 pp. ISBN: 0029342104 9780029342107.

Weinstock M. (2011). The Metabolism of the City: The Mathematics of Networks and Urban Surfaces. *Architectural Design* **81**, 102–107. doi: 10.1002/ad.1275, ISSN: 1554-2769.

Weisz H., and J.K. Steinberger (2010). Reducing energy and material flows in cities. *Current Opinion in Environmental Sustainability* **2**, 185–192. doi: 10.1016/j.cosust.2010.05.010, ISSN: 18773435.

Weitz J. (2003). *Jobs-Housing Balance*. American Planning Association, Washington, D.C., 41 pp.

West G.B., J.H. Brown, and B.J. Enquist (1999). The Fourth Dimension of Life: Fractal Geometry and Allometric Scaling of Organisms. *Science* **284**, 1677–1679. doi: 10.1126/science.284.5420.1677, ISSN: 0036-8075, 1095–9203.

West J.J., S.J. Smith, R.A. Silva, V. Naik, Y. Zhang, Z. Adelman, M.M. Fry, S. Anenberg, L.W. Horowitz, and J.-F. Lamarque (2013). Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nature Climate Change* **3**, 885–889. doi: 10.1038/nclimate2009, ISSN: 1758-678X.

Wheeler S.M. (2008). State and Municipal Climate Change Plans: The First Generation. *Journal of the American Planning Association* **74**, 481–496. doi: 10.1080/01944360802377973, ISSN: 0194-4363.

White P., J.S. Golden, K.P. Biligiri, and K. Kaloush (2010). Modeling climate change impacts of pavement production and construction. *Resources, Conservation and Recycling* **54**, 776–782. doi: 10.1016/j.resconrec.2009.12.007, ISSN: 09213449.

Whitford V., A.R. Ennos, and J.F. Handley (2001). "City form and natural process"—indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape and Urban Planning* **57**, 91–103. doi: 10.1016/S0169-2046(01)00192-X, ISSN: 0169-2046.

Wiedenhofer D., M. Lenzen, and J.K. Steinberger (2013). Energy requirements of consumption: Urban form, climatic and socio-economic factors, rebounds and their policy implications. *Energy Policy* **63**, 696–707. doi: 10.1016/j.enpol.2013.07.035, ISSN: 03014215.

Willson R.W. (1995). Suburban Parking Requirements: A Tacit Policy for Automobile Use and Sprawl. *Journal of the American Planning Association* **61**, 29–42. doi: 10.1080/01944369508975617, ISSN: 0194-4363, 1939–0130.

Wilson E. (2009). Multiple Scales for Environmental Intervention: Spatial Planning and the Environment under New Labour. *Planning Practice and Research* **24**, 119–138. doi: 10.1080/02697450902742205, ISSN: 0269-7459.

Wirth L. (1938). Urbanism as a Way of Life. *American Journal of Sociology* **44**, 1–24. doi: 10.2307/2768119, ISSN: 0002-9602.

Woo M., and J.-M. Guldmann (2011). Impacts of Urban Containment Policies on the Spatial Structure of US Metropolitan Areas. *Urban Studies* **48**, 3511–3536. doi: 10.1177/0042098011399594, ISSN: 0042-0980, 1360–063X.

World Bank (2005). *Dynamics of Urban Expansion*. Available at: http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/dynamics_urban_expansion.pdf.

World Bank (2009). *World Development Report 2009: Reshaping Economic Geography*. World Bank, Washington, D.C., 383 pp. ISBN 9978-0-8213-7607-2.

World Bank (2010). *Cities and Climate Change: An Urgent Agenda*. The World Bank, Washington, D.C., 306 pp. Available at: http://siteresources.worldbank.org/INTUWM/Resources/340232-1205330656272/CitiesandClimateChange.pdf.

World Bank (2013). Health Nutrition and Population Statistics. Available at: http://data.worldbank.org/data-catalog/health-nutrition-and-population-statistics.

Wright L.A., J. Coello, S. Kemp, and I. Williams (2011). Carbon footprinting for climate change management in cities. *Carbon Management* **2**, 49–60. doi: 10.4155/cmt.10.41, ISSN: 1758-3004.

Yalçın M., and B. Lefèvre (2012). Local Climate Action Plans in France: Emergence, Limitations and Conditions for Success. *Environmental Policy and Governance* **22**, 104–115.

Yang J., and R. Gakenheimer (2007). Assessing the transportation consequences of land use transformation in urban China. *Habitat International* **31**, 345–353. doi: 10.1016/j.habitatint.2007.05.001, ISSN: 0197-3975.

Yang F., S.S.Y. Lau, and F. Qian (2010). Summertime heat island intensities in three high-rise housing quarters in inner-city Shanghai China: Building layout, density and greenery. *Building and Environment* **45**, 115–134. doi: 10.1016/j.buildenv.2009.05.010, ISSN: 0360-1323.

Yang P.P.-J., and S.H. Lew (2009). An Asian Model of TOD: The Planning Integration in Singapore. In: *Transit Oriented Development: Making It Happen*. C. Curtis, J.L. Renne, L. Bertolini, (eds.), Ashgate, Surrey, England, pp. 91–106. ISBN: 9780754673156.

Yescombe E.R. (2007). *Public-Private Partnerships: Principles of Policy and Finance*. Elsevier; Butterworth-Heinemann, Amsterdam; Boston: Burlington, Mass, 350 pp. ISBN: 9780750680547.

Yu W., R. Pagani, and L. Huang (2012). CO_2 emission inventories for Chinese cities in highly urbanized areas compared with European cities. *Energy Policy* **47**, 298–308. doi: 10.1016/j.enpol.2012.04.071, ISSN: 0301-4215.

Zeemering E. (2012). Recognising interdependence and defining multi-level governance in city sustainability plans. *Local Environment* **17**, 409–424. doi: 10.1080/13549839.2012.678315, ISSN: 1354-9839.

Zegras C. (2003). Financing transport infrastructure in developing country cities: Evaluation of and lessons from nascent use of impact fees in Santiago de Chile. *Transportation Research Record: Journal of the Transportation Research Board* **1839**, 81–88. Available at: http://trb.metapress.com/index/9366673J23868L03.pdf.

Zegras C. (2010). The Built Environment and Motor Vehicle Ownership and Use: Evidence from Santiago de Chile. *Urban Studies* **47**, 1793–1817. doi: 10.1177/0042098009356125, ISSN: 0042-0980, 1360–063X.

Zeng X., Y. Ma, and L. Ma (2007). Utilization of straw in biomass energy in China. *Renewable and Sustainable Energy Reviews* **11**, 976–987. doi: 10.1016/j.rser.2005.10.003, ISSN: 1364-0321.

Zhang M. (2004). The role of land use in travel mode choice: Evidence from Boston and Hong Kong. *Journal of the American Planning Association* **70**, 344–360.

Zhang M. (2007). Chinese edition of transit-oriented development. *Journal of the Transportation Research Board* **2038**, 120–127. doi: 10.3141/2038-16.

Zhang M., H. Mu, and Y. Ning (2009). Accounting for energy-related CO_2 emission in China, 1991–2006. *Energy Policy* **37**, 767–773. doi: 10.1016/j.enpol.2008.11.025, ISSN: 0301-4215.

Zhang M., and L. Wang (2013). The impacts of mass transit on land development in China: The case of Beijing. *Research in Transportation Economics* **40**, 124–133. doi: 10.1016/j.retrec.2012.06.039, ISSN: 0739-8859.

Zhao M., Z. Kong, F.J. Escobedo, and J. Gao (2010). Impacts of urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China. *Journal of Environmental Management* **91**, 807–813. doi: 10.1016/j.jenvman.2009.10.010, ISSN: 0301-4797.

Zheng S., Y. Fu, and H. Liu (2006). Housing-choice hindrances and urban spatial structure: Evidence from matched location and location-preference data in Chinese cities. *Journal of Urban Economics* **60**, 535–557. doi: 10.1016/j.jue.2006.05.003, ISSN: 0094-1190.

Zheng S., Y. Fu, and H. Liu (2009). Demand for Urban Quality of Living in China: Evolution in Compensating Land-Rent and Wage-Rate Differentials. *The Journal of Real Estate Finance and Economics* **38**, 194–213. doi: 10.1007/s11146-008-9152-0, ISSN: 0895-5638, 1573–045X.

Zheng S., R. Wang, E.L. Glaeser, and M.E. Kahn (2010). The greenness of China: household carbon dioxide emissions and urban development. *Journal of Economic Geography* **11**, 761–792. doi: 10.1093/jeg/lbq031, ISSN: 1468-2702, 1468–2710.

Zhou B.B., and K.M. Kockelman (2008). Self-selection in home choice: Use of treatment effects in evaluating relationship between built environment and travel behavior. *Transportation Research Record: Journal of the Transportation Research Board* **2077**, 54–61. doi: 10.3141/2077-08.

Zimmerman R., and C. Faris (2011). Climate change mitigation and adaptation in North American cities. *Current Opinion in Environmental Sustainability* **3**, 181–187. doi: 10.1016/j.cosust.2010.12.004, ISSN: 1877-3435.

Zipf G.K. (1949). *Human Behavior and the Principle of Least Effort*. Addison-Wesley Press, Oxford, England, 573 pp.

Zulu L.C. (2010). The forbidden fuel: Charcoal, urban woodfuel demand and supply dynamics, community forest management and woodfuel policy in Malawi. *Energy Policy* **38**, 3717–3730. doi: 10.1016/j.enpol.2010.02.050, ISSN: 0301-4215.

13

International Cooperation: Agreements & Instruments

Coordinating Lead Authors:
Robert Stavins (USA), Zou Ji (China)

Lead Authors:
Thomas Brewer (USA), Mariana Conte Grand (Argentina), Michel den Elzen (Netherlands), Michael Finus (Germany/UK), Joyeeta Gupta (Netherlands), Niklas Höhne (Germany), Myung-Kyoon Lee (Republic of Korea), Axel Michaelowa (Germany/Switzerland), Matthew Paterson (Canada), Kilaparti Ramakrishna (Republic of Korea/USA), Gang Wen (China), Jonathan Wiener (USA), Harald Winkler (South Africa)

Contributing Authors:
Daniel Bodansky (USA), Gabriel Chan (USA), Anita Engels (Germany), Adam Jaffe (USA/New Zealand), Michael Jakob (Germany), T. Jayaraman (India), Jorge Leiva (Chile), Kai Lessmann (Germany), Richard Newell (USA), Sheila Olmstead (USA), William Pizer (USA), Robert Stowe (USA), Marlene Vinluan (Philippines)

Review Editors:
Antonina Ivanova Boncheva (Mexico/Bulgaria), Jennifer Morgan (USA)

Chapter Science Assistant:
Gabriel Chan (USA)

This chapter should be cited as:

Stavins R., J. Zou, T. Brewer, M. Conte Grand, M. den Elzen, M. Finus, J. Gupta, N. Höhne, M.-K. Lee, A. Michaelowa, M. Paterson, K. Ramakrishna, G. Wen, J. Wiener, and H. Winkler, 2014: International Cooperation: Agreements and Instruments. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Contents

Executive Summary

This chapter critically examines and evaluates the ways in which agreements and instruments for international cooperation to address global climate change have been and can be organized and implemented, drawing upon evidence and insights found in the scholarly literature. The retrospective analysis of international cooperation in the chapter discusses and quantifies what has been achieved to date and surveys the literature on explanations of successes and failures.

International cooperation is necessary to significantly mitigate climate change impacts (*robust evidence, high agreement*). This is principally due to the fact that greenhouse gases (GHGs) mix globally in the atmosphere, making anthropogenic climate change a global commons problem. International cooperation has the potential to address several challenges: multiple actors that are diverse in their perceptions of the costs and benefits of collective action, emissions sources that are unevenly distributed, heterogeneous climate impacts that are uncertain and distant in space and time, and mitigation costs that vary. [Section 13.2.1.1, 13.15]

International cooperation on climate change has become more institutionally diverse over the past decade (*robust evidence, high agreement*). The United Nations Framework Convention on Climate Change (UNFCCC) remains a primary international forum for climate negotiations, but other institutions have emerged at multiple scales: global, regional, national, and local, as well as public-private initiatives and transnational networks. [13.3.1, 13.4.14, 13.5, 13.12] This institutional diversity arises in part from the growing inclusion of climate change issues in other policy arenas (e.g., sustainable development, international trade, and human rights). These and other linkages create opportunities, potential co-benefits, or harms that have not yet been thoroughly examined. Issue linkage also creates the possibility of forum shopping and increased negotiation costs, which could distract from or dilute the performance of international cooperation toward climate goals. [13.3, 13.4, 13.5]

Existing and proposed international climate agreements vary in the degree to which their authority is centralized (*robust evidence, high agreement*). The range of centralized formalization spans: strong multilateral agreements (such as the Kyoto Protocol targets), harmonized national policies (such as the Copenhagen/Cancún pledges), and decentralized but coordinated national policies (such as planned linkages of national and sub-national emissions trading schemes). [13.4.1, 13.4.3] Additionally, potential agreements vary in their degree of legal bindingness [13.4.2.1]. Three other design elements of international agreements have particular relevance: goals and targets, flexible mechanisms, and equitable methods for effort sharing. [13.4.2]

The UNFCCC is currently the only international climate policy venue with broad legitimacy, due in part to its virtually universal membership (*robust evidence, medium agreement*). The UNFCCC continues to develop institutions and systems for governance of climate change. [13.2.2.4, 13.3.1, 13.4.1.4, 13.5]

Non-UN forums and coalitions of non-state actors, such as private businesses and city-level governments, are also contributing to international cooperation on climate change (*medium evidence, medium agreement*). These forums and coalitions address issues including deforestation, technology transfer, adaptation, and fossil fuel subsidies. However, their actual mitigation performance is unclear. [13.5.1.3, 13.13.1.4]

International cooperation may have a role in stimulating public investment, financial incentives, and regulations to promote technological innovation, thereby more actively engaging the private sector with the climate regime (*medium evidence, medium agreement*). Technology policy can help lower mitigation costs, thereby increasing incentives for participation and compliance with international cooperative efforts, particularly in the long run. Equity issues can be affected by domestic intellectual property rights regimes, which can alter the rate of both technology transfer and the development of new technologies. [13.3, 13.9, 13.12]

In the absence of—or as a complement to—a binding, international agreement on climate change, policy linkages among existing and nascent regional, national, and sub-national climate policies offer potential climate change mitigation and adaptation benefits (*medium evidence, medium agreement*) [13.3.1, 13.5.1.3]. Direct and indirect linkages between and among sub-national, national, and regional carbon markets are being pursued to improve market efficiency. Yet integrating climate policies raises a number of concerns about the performance of a system of linked legal rules and economic activities. Linkage between carbon markets can be stimulated by competition between and among public and private governance regimes, accountability measures, and the desire to learn from policy experiments. [13.3.1, 13.5.3, 13.6, 13.7, 13.13.2.3, Figure 13.4]

While a number of new institutions are focused on adaptation funding and coordination, adaptation has historically received less attention than mitigation in international climate policy, but inclusion of adaptation is increasingly important to reduce damages and may engage a greater number of countries (*robust evidence, medium agreement*). Other possible complementarities and tradeoffs between mitigation and adaptation, particularly the temporal distribution of actions, are not well-understood. [13.2, 13.3.3, 13.5.1.1, 13.14]

Participation in international cooperation on climate change can be enhanced by monetary transfers, market-based mechanisms, technology transfer, and trade-related measures (*robust evidence, medium agreement*). These mechanisms to enhance participation, along with compliance, legitimacy, and flexibility, affect the institutional feasibility of international climate policy. [13.2.2.4, 13.3.3, 13.8.1, 13.9.2]

International trade can offer a range of positive and negative incentives to promote international cooperation on climate change (*robust evidence, medium agreement*). Three issues are key to developing constructive relationships between international trade and climate agreements: how existing trade policies and rules can be modified to be more climate friendly; whether border adjustment measures (BAMs) or other trade measures can be effective in meeting the goals of international climate agreements; whether the UNFCCC, World Trade Organization (WTO), hybrid of the two, or a new institution is the best forum for a trade-and-climate architecture. [13.8]

Climate change policies can be evaluated using four criteria: environmental effectiveness, aggregate economic performance, distributional impacts, and institutional feasibility. These criteria are grounded in several principles: maximizing global net benefits; equity and the related principles of distributive justice and common but differentiated responsibilities and respective capabilities (CBDRRC); precaution and the related principles of anticipation, and prevention of future risks; and sustainable development. These criteria may at times conflict, forcing tradeoffs among them. [13.2.1, 13.2.2]

International cooperation has produced political agreement regarding a long-term goal of limiting global temperature increase to no more than 2 °C above pre-industrial levels, but the overall level of mitigation achieved to date by cooperation appears inadequate to achieve this goal (*robust evidence, medium agreement*). Mitigation pledges by individual countries in the Copenhagen-Cancún regime, if fully implemented, will help reduce emissions in 2020 to below the projected business-as-usual level, but are unlikely to attain an emission level in 2020 consistent with cost-effective pathways, based on the immediate onset of mitigation, that achieve the long-term 2 °C goal with a greater than 50 % probability. The contribution of international cooperation outside of the UNFCCC is largely not quantified. [13.2.2.1, 13.13.1]

The Kyoto Protocol was the first binding step toward implementing the principles and goals provided by the UNFCCC, but it has had limited effects on global emissions because some countries did not ratify the Protocol, some Parties did not meet their commitments, and its commitments applied to only a portion of the global economy (*medium evidence, low agreement*). The Parties collectively surpassed their collective emission reduction target in the first commitment period, but the Protocol credited emissions reductions that would have occurred even in its absence. The Kyoto Protocol does not directly influence the emissions of non-Annex I countries, which have grown rapidly over the past decade. [13.13.1.1]

The flexible mechanisms under the Kyoto Protocol have generally helped to improve its economic performance, but their environmental effectiveness is less clear (*medium evidence, medium agreement*). The Clean Development Mechanism (CDM) created a market for emissions offsets from developing countries, generating credits equivalent to nearly 1.4 billion tCO_2eq as of October 2013, many of which have been generated by low-cost mitigation technologies. The CDM showed institutional feasibility of a project-based market mechanism under widely varying circumstances. The CDM's environmental effectiveness has been mixed due to concerns about the additionality of projects, the validity of baselines, the possibility of emissions leakage, and recent price decreases. Its distributional impacts were limited due to the concentration of projects in a limited number of countries. The Protocol's other flexible mechanisms, Joint Implementation and International Emissions Trading, have been undertaken both by governments and private market participants, but have raised concerns related to government sales of emission units. [13.7.2, 13.13.1.2]

Recent UNFCCC negotiations have sought to include more ambitious mitigation commitments from countries with commitmments under the Kyoto Protocol, mitigation contributions from a broader set of countries, and new finance and technology mechanisms (*medium evidence, low agreement*). Under the 2010 Cancún Agreement, developed countries formalized voluntary pledges of quantified, economy-wide emission reduction targets and some developing countries formalized voluntary pledges to mitigation actions. The distributional impact of the Agreement will depend in part on the magnitude and sources of financing, including the successful fulfilment by developed countries of their expressed joint commitment to mobilize 100 billion USD per year by 2020 for climate action in developing countries. Under the 2011 Durban Platform for Enhanced Action, delegates agreed to craft a future legal regime that would be 'applicable to all Parties … under the Convention' and would include substantial new financial support and technology arrangements to benefit developing countries, but the delegates did not specify means for achieving those ends. [13.5.1.1, 13.11, 13.13.1.3]

The Montreal Protocol, aimed at protecting the stratospheric ozone layer, has also achieved significant reductions in global GHG emissions (*robust evidence, high agreement*). The Montreal Protocol set limits on emissions of ozone-depleting gases that are also potent GHGs, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Substitutes for those ozone-depleting gases (such as hydrofluorocarbons (HFCs), which are not ozone-depleting) may also be potent GHGs. Lessons learned from the Montreal Protocol, for example, about the effect of financial and technological transfers on broadening participation in an international environmental agreement, could be of value to the design of future international climate change agreements. [13.3.3, 13.3.4, 13.13.1.4]

Assessment of proposed cooperation structures reinforces the finding that there will likely be tradeoffs between the four criteria, as they will inevitably conflict in some elements of any agreement (*medium evidence, high agreement*). Assessment of proposed climate policy architectures reveals important tradeoffs that depend on the specific design elements and regulatory mechanisms of a proposal. For example, there is a potential tradeoff between broad participation and the institutional feasibility of an ambitious environmental performance goal. The extent of this tradeoff may depend on financial transfers, national enforcement mechanisms, and the distribution and sharing of mitigation efforts. [13.2.2.5, 13.3.3, 13.13.1.4, 13.13.2]

Increasing interest in solar radiation management (SRM) and carbon dioxide removal (CDR) as strategies to mitigate the harms of climate change, pose new challenges for international cooperation (*medium evidence, high agreement*). Whereas emissions abatement poses challenges of engaging multilateral action to cooperate, SRM may pose challenges of coordinating research and restraining unilateral deployment of measures with potentially adverse side-effects. [13.4.4]

Gaps in knowledge and data: (1) comparisons among proposals in terms of aggregate and country-level costs and benefits per year, with incorporation of uncertainty; (2) assessment of the overall effect of emerging intergovernmental and transnational arrangements, including 'hybrid' approaches; (3) understanding of complementarities and tradeoffs between policies affecting mitigation and adaptation; (4) understanding how international cooperation on climate change can help achieve co-benefits and development goals, including capacity building approaches; (5) understanding the factors that affect national decisions to join and form agreements.

13.1 Introduction

Due to global mixing of greenhouse gases (GHGs) in the atmosphere, anthropogenic climate change is a global commons problem. For this reason, international cooperation is necessary to achieve significant progress in mitigating climate change. Drawing on published research, this chapter critically examines and evaluates the ways in which agreements and instruments for international cooperation have been and can be organized and implemented. The retrospective analysis of international cooperation in the chapter quantifies and discusses what has been achieved to date, and surveys the literature on explanations of successes and failures.

The scope of the chapter is defined by the range of feasible international agreements and other policy instruments for cooperation on climate-change mitigation and adaptation. The disciplinary scope spans the social sciences of economics, political science, international relations, law, public policy, psychology, and sociology; relevant humanities, including history and philosophy; and—where relevant to the discussion—the natural sciences. Where appropriate, the chapter synthesizes literature that utilizes econometric modelling, integrated modelling, game theory, comparative case studies, legal analysis, and political analysis. This chapter focuses on research and policy developments since the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007).

13.2 Framing concepts for an assessment of means for international cooperation

This section introduces the concept of a global commons problem to frame the challenge of international cooperation on climate change, principles for designing effective international climate policy, and criteria for evaluating these policies.

13.2.1 Framing concepts and principles

13.2.1.1 The global commons and international climate cooperation

Climate change is a global commons problem, meaning reduction in emissions by any jurisdiction carries an economic cost, but the benefits (in the form of reduced damages from climate change) are spread around the world—although unevenly—due to GHG emissions mixing globally in the atmosphere. Mitigation of climate change is non-excludable, meaning it is difficult to exclude any individual or institution from the shared global benefits of emissions reduction undertaken by any localized actor. Also, these benefits are non-rival, meaning they may be enjoyed by any number of individuals or institutions at the same time, without reducing the extent of the benefit any one of them receives. These public good characteristics of climate protection (non-excludability and non-rivalry) create incentives for actors to 'free ride' on other actors' investments in mitigation. Therefore, lack of ambition in mitigation and overuse of the atmosphere as a receptor of GHGs are likely.

Incentives to free ride on climate protection have been analyzed extensively and are well-understood (Gordon, 1954; Hardin, 1968; Stavins, 2011). The literature suggests that in some cases, effective common property management of local open-access resources can limit or even eliminate overuse (Ostrom, 2001; Wiener, 2009). Effective common property management of the atmosphere would require applying such management at a global level, by allocating rights to emit and providing disincentives for overuse through sanctions or pricing emissions (Byrne and Glover, 2002; Wiener, 2009).

Enhancing production of public goods may be achieved by internalizing external costs (i.e., those costs not incorporated into market prices) or through legal remedies. Economic instruments can incorporate external costs and benefits into prices, providing incentives for private actors to more optimally reduce external costs and increase external benefits (Baumol and Oates, 1988; Nordhaus, 2006; Buchholz et al., 2012). Legal remedies may include seeking injunctive relief or compensatory payments (IPCC, 2007, Chapter 13; Faure and Peeters, 2011; Haritz, 2011)

International cooperation is necessary to significantly mitigate climate change because of the global nature of the problem (WCED, 1987; Kaul et al., 1999, 2003; Byrne and Glover, 2002; Barrett, 2003; Stewart and Wiener, 2003; Sandler, 2004) Cooperation has the potential to address several challenges: multiple actors that are diverse in their perceptions of the costs and benefits of collective action; emissions sources that are unevenly distributed; heterogeneous climate impacts that are uncertain and distant in space and time; and mitigation costs that vary (IPCC, 2001, pp. 607–608).

In the absence of universal collective action, smaller groups of individual actors may be able to organize schemes to supply public goods, particularly if actors know each other well, expect repeated interactions, can exclude non-members, and can monitor and sanction non-compliance in the form of either overconsumption or underproduction (Eckersley, 2012; McGee, 2011; Nairn, 2009; Ostrom, 1990, 2010a; b, 2011; Weischer et al., 2012). Some authors are optimistic regarding such 'minilateralism' (e.g., Keohane and Victor, 2011; on the term, see Eckersley, 2012) and others are more sceptical (e.g., Depledge and Yamin, 2009; Winkler and Beaumont, 2010) . Section 13.3 discusses the literature on coalitions in more detail.

Because there is no world government, each country must voluntarily consent to be bound by any international agreement. If these are to be effective, the agreements must be attractive enough to gain broad participation (Barrett, 2003, 2007; Stewart and Wiener, 2003; Schmalensee, 2010; Brousseau et al., 2012). Considering the relationship between mitigation costs and climate benefits discussed above, there is insufficient incentive for actors at any level to reduce emissions significantly in the absence of international cooperation. Behavioural research, however, indicates that individuals are sometimes motivated to cooperate (and to punish those who do not) to a degree greater than strict rational choice models predict (Camerer, 2003; Andreoni and Samuelson, 2006). This may explain some of the observed policies being adopted to reduce GHG emissions at the national, subnational, firm, and individual level. Moreover, even under the assumption of rational action, some emission reductions can occur without cooperation due to positive externalities of otherwise self-beneficial actions, or co-benefits, such as actions to reduce energy expenditures, enhance the security of energy supply, reduce local air pollution, improve land use, and protect biodiversity (Seto et al., 2012). Co-benefits of climate protection are receiving increasing attention in the literature (Rayner, 2010; Dubash, 2009; UNEP, 2013b). However, policies designed to address climate change mitigation may also have adverse side-effects. See Section 4.8 and 6.6 for an overview of the discussion of co-benefits and adverse side-effects throughout this report.

13.2.1.2 Principles

Several principles have been advanced to shape international climate change policies. The IPCC Third Assessment Report (TAR) (IPCC, 2001) discusses principles and mentions some criteria for evaluation of policies, whereas the AR4 (IPCC, 2007), clearly differentiates principles from criteria. Principles serve as guides to design climate policies, while criteria are specific standards by which to evaluate them. The roles and applications of principles and criteria are further elaborated in Chapter 3 of this report.

Sets of principles are enumerated and explained in multiple international climate change fora, including the Rio Declaration on Environment and Development (UNEP, 1992) and the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 1992). In the latter, the principles listed explicitly include: 'equity' and 'common but differentiated responsibilities and respective capabilities' (CBDRRC) (Article 3(1)), relative needs, vulnerability, burdens in countries of differing wealth (Article 3(2)), precaution and 'cost-effective[ness] so as to ensure global benefits at the lowest possible cost' (Article 3(3)), 'sustainable development' (Article 3(4)), and cooperation (Article 3(5)).

Principles of climate change policy relevant for international cooperation can be grouped into several broad categories. First, the principle of maximizing global net benefits makes the tradeoff between aggregate compliance costs and aggregate performance benefits explicit. The principle also incorporates the notion of maximizing co-benefits of climate action (Stern, 2007; Nordhaus, 2008; Bosetti et al., 2010; Rayner, 2010; Dubash, 2009) (see also Section 3.6.3). A related concept is that of cost-effectiveness, which allows for policies with the same level of performance in terms of aggregate benefits to be compared on the dimension of aggregate cost (IPCC, 2001, 2007, Chapter 13). See Section 6.6 for applied scenario studies.

Second, equity is a principle that emphasizes distributive justice across and within countries and across and within generations (Vanderheiden, 2008; Baer et al., 2009; Okereke, 2010; Posner and Sunstein, 2010; Posner and Weisbach, 2010; Somanathan, 2010; Cao, 2010c). It includes evaluating the procedures used to reach an agreement as well as the achieved outcomes. This principle may also apply in a broader assessment of well-being (Sen, 2009; Cao, 2010a). The principle of CBDRRC has been central in international climate negotiations (Rajamani, 2006, 2011a; Gupta and Sanchez, 2013). The literature refers to the varied historic responsibility—and current capability and capacity—of countries with regard to impacts of and action to address climate change (Jacoby et al., 2010; Rajamani, 2006, 2012b; Höhne et al., 2008; Dellink et al., 2009; den Elzen et al., 2013b). Some literature assesses how the principle might be applied to actors' diverse needs (Jonas, 1984; Dellink et al., 2009), including the specific needs and vulnerabilities of developing countries (Rong, 2010; Smith et al., 2011; Bukovansky et al., 2012). Recent literature suggests that this principle's application may be more nuanced as patterns of development, emissions, and impacts evolve (Bukovansky et al., 2012; Deleuil, 2012; Müller and

Mahadev, 2013; Winkler and Rajamani, 2013). The literature describes competing views regarding the meaning of this principle in terms of its legal status, operational significance, and the obligations it may entail (Höhne et al., 2006; Halvorssen, 2007; O'Brien, 2009; Winkler et al., 2009; Winkler, 2010; Hertel, 2011). The principle of CBDRRC is further analyzed in Sections 3.3 and 4.6.

Third, the principle of precaution emphasizes anticipation and prevention of future risks, even in the absence of full scientific certainty about the impacts of climate change (Bodansky, 2004; Wiener, 2007; Urueña, 2008). Some see precaution as a strategy for effective action across diverse uncertain scenarios (Barrieu and Sinclair-Desgagné, 2006; World Bank, 2010), although the application of precaution varies across risks and countries (Hammitt, 2010). A key ongoing debate concerns whether or not this principle implies the need for stringent climate change policies as an insurance against potentially catastrophic outcomes, even if they may have very low probability (Weitzman, 2007, 2009, 2011; Pindyck, 2011; Nordhaus, 2011). The application of the precautionary principle to climate risk is further discussed in Section 2.5.5.

Fourth, the principle of sustainable development, broadly defined, emphasizes consideration of the socioeconomic needs of future generations in making decisions about current resource use (IPCC, 2007, Chapter 12; World Bank, 2010). For a detailed discussion of the literature on sustainable development, see Section 4.2.1.

13.2.2 Potential criteria for assessing means of international cooperation

The principles elaborated above can be translated into criteria to evaluate forms of international cooperation, thereby assisting in the design of a distribution of efforts intended to solve the collective action problem of climate protection. The AR4 put forth one set of criteria: environmental effectiveness, cost-effectiveness, distributional considerations, and institutional feasibility (IPCC, 2007, pp. 751–752). As 'metrics of success', these evaluation criteria can be applied in the context of both ex-post evaluations of actual performance and ex-ante assessments of proposed cooperation (Hammitt, 1999; Fischer and Morgenstern, 2010). Below, this section describes four evaluation criteria that are applied in Section 13.13 to assess existing and proposed forms of international cooperation to address climate change mitigation. These criteria are subject to caveats, which are detailed in Section 13.13.

13.2.2.1 Environmental effectiveness

The environmental effectiveness of a climate change mitigation policy is the extent to which it achieves its objective to reduce the causes and impacts of climate change. Environmental effectiveness can be achieved by reducing anthropogenic sources of GHG emissions, removing GHGs from the atmosphere, or reducing the impacts of climate change directly through increased resilience. A primary objective of international cooperation has been to stabilize GHG concentrations at levels sufficient to "prevent dangerous anthropogenic interference with the climate system," in the words of the UNFCCC Article 2 (1992). This would require action within a time-frame sufficient to "allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (UNFCCC, 1992), Article 2). The Kyoto Protocol established specific emission-reduction targets for developed countries, while the Copenhagen Accord and Cancún Agreements expressed the environmental objective in terms of global average temperature increase. In addition to endorsing mitigation targets by developed countries and mitigation actions by developing countries, the Copenhagen and Cancún agreements recognized a goal of limiting increases in average global temperature to 2 °C above pre-industrial levels (UNFCCC, 2009a, 2010, 2011a).

13.2.2.2 Aggregate economic performance

Measuring the aggregate economic performance of a climate policy requires considering both its economic efficiency and its cost-effectiveness. Economic efficiency refers to the maximization of net benefits, the difference between total social benefits and total social costs (Stern, 2007; Nordhaus, 2008; Bosetti et al., 2010).

Cost-effectiveness refers to the ability of a policy to attain a prescribed level of environmental performance at least cost, taking into account impacts on dynamic efficiency, notably technological innovation (Jaffe and Stavins, 1995). Unlike net benefit assessment, cost-effectiveness analysis takes the environmental performance of a policy as given and seeks the least-cost strategy to attain it (Hammitt, 1999). While analysis of a policy in terms of its cost-effectiveness still requires environmental performance of the policy to be quantified, it does not require environmental performance benefits to be monetized. Thus, analysis of a policy's cost-effectiveness may be more feasible than analysis of a policy's economic efficiency in the case of climate change, as some social benefits of climate-change mitigation are difficult to monetize.

13.2.2.3 Distributional and social impacts

Distributional equity and fairness may be considered important attributes of climate policy because of their impact on measures of well-being (Posner and Weisbach, 2010) and political feasibility (Jacoby et al., 2010; Gupta, 2012). Distributional equity relates to burden- and benefit-sharing across countries and across time. Section 4.2.2 puts forward three justifications for considering distributional equity—legal, environmental effectiveness, and moral. The framing in Section 4.2 also identifies a relatively small set of core equity principles: responsibility, capacity, the right to sustainable development, and equality. These may be modelled with quantitative indicators, as discussed in Section 6.3.6.6. The moral justification draws on ethical principles, which are reflected in the principles of the Convention (see Section 13.2.1.2; and detailed treatment of the literature on ethics in Section 3.2).

Another dimension of distributional equity is the possibility for mitigation actions in one jurisdiction to have positive or negative consequences in another jurisdiction. This phenomenon, sometimes referred to as 'response measures' or as 'spillover effects' (see WGIII AR4 Glossary), can lead to an unequal distribution of the impacts of climate change mitigation actions themselves. A plausible example of a spillover effect is the impact of emissions reductions in developed countries lowering the demand for fossil fuels and thus decreasing their prices, leading to more use of such fuels and greater emissions in developing nations, partially off-setting the original cuts (Bauer et al., 2013) This dynamic can also be important for countries with large endowments of conventional oil and gas that depend on export revenues. These countries may lose energy export revenue as a result of climate policies enacted in other countries (Kalkuhl and Brecha, 2013; Bauer et al., 2013). Additionally, climate policies could also reduce international coal trading (Jewell et al., 2013). See also Sections 6.3.6, 14.4.2, and 15.5.2 for further discussion of spillover effects.

13.2.2.4 Institutional feasibility

The institutional feasibility of international climate policy may depend upon agreement among national governments and between governments and intergovernmental bodies (Wiener, 2009; Schmalensee, 2010). Institutional feasibility is closely linked to domestic political feasibility, because domestic political conditions affect participation in, and compliance with, international climate policies. This has been addressed in the literature on 'two-level' games (Kroll and Shogren, 2009; Hafner-Burton et al., 2012). Four sub-criteria of institutional feasibility can also be considered: *participation*, *compliance*, *legitimacy*, and *flexibility*.

First, *participation* in an international climate agreement might refer to the number of parties, geographical coverage, or the share of global GHG emissions covered. Participating parties might vary with regard to the nature and specificity of their commitments (e.g., actions versus quantitative emissions-reduction targets). Sovereign states are not bound by an international treaty or other arrangement unless they consent to participate. The literature has examined a broad array of incentives to promote breadth of participation in international agreements (Barrett, 2003; Barrett and Stavins, 2003; Stewart and Wiener, 2003; Hall et al., 2010; Victor, 2010; World Bank, 2010; Olmstead and Stavins, 2012). These incentives can be positive (e.g., financial support or technology transfers) or negative (e.g., trade sanctions). Some authors have suggested that participation limited to countries with the highest emissions enhances institutional feasibility (Leal-Arcas, 2011) and that incentive-based emissions-permit allocations, or rules requiring participation of key players, may enable larger coalitions (Dellink et al., 2008; Dellink, 2011).

Second, institutional feasibility is also partly determined by the *compliance* of participating countries with an agreement's provisions. Mechanisms to ensure compliance, in turn, affect decisions to participate, as well as long-term performance (Barrett, 2003). Incentives for encouraging compliance can be built into flexible mechanisms, such as tradable permit systems (Wiener, 2009; Ismer and Neuhoff, 2009; Keohane and Raustiala, 2010). Compliance is fundamentally problematic in international agreements, as it is difficult to establish an authority that can legitimately and effectively impose sanctions upon sovereign national governments. Despite that, indirect negative consequences of non-compliance can arise within the regime established by the agreement, or in other regimes, for example, adverse voting behaviour in international forums or reduction in foreign aid (Heitzig et al., 2011).

Third, *legitimacy* is a key component of institutional feasibility. Parties to a cooperative agreement must have reason to accept and implement decisions made under the agreement, meaning they must believe that the relevant regime represents them fairly. Legitimacy depends on the shared understanding both that the substantive rules (outputs) and decision-making procedures (inputs) are fair, equitable, and beneficial (Scharpf, 1999), and thus that other regime members will continue to cooperate (Ostrom, 1990, 2011). In practice, the legitimacy of substantive rules is typically based on whether parties evaluate positively the results of an authority's policies, while procedural legitimacy is typically based on the existence of proper input mechanisms of participation and consultation for the parties participating in an agreement (Stevenson and Dryzek, 2012).

Finally, the institutional feasibility of international climate policy depends in part on whether the institutions relevant for a policy can develop *flexibility* mechanisms—which typically require that the institutions themselves are flexible or adjustable. It may be important to be able to adapt to new information or to changes in economic and political circumstances. The institutionalization of learning among actors, which is referred to as 'social learning' in the literature of environmental governance (Pahl-Wostl et al., 2007), is an important aspect of success, enabling adaptation to changing circumstances. While institutional arrangements that incorporate a purposive process of experimentation, evaluation, learning, and revision may be costly, policies that do not incorporate these steps may be overly rigid in the face of change and therefore potentially even more costly (Greenstone, 2009; Libecap, 2011). Another area of current debate and research is the question of whether increased flexibility in designing obligations for states helps them align their international obligations more readily with domestic political constraints (von Stein, 2008; Hafner-Burton et al., 2012). This suggests that designing international climate policies involves a balance between the benefits of flexibility and the costs of regulatory uncertainty (Goldstein and Martin, 2000; Brunner et al., 2012). Chapter 2, for example in Section 2.6.5.1, goes into more depth on problems related to regulatory uncertainty.

Box 13.1 | International agreements and developing countries

The United Nations Framework Convention on Climate Change (UNFCCC) is a statement of aspirations, principles, goals, and the means to meet commitments. The Kyoto Protocol of the UNFCCC included, for the first time, binding mitigation commitments—for nations listed in its Annex B. Other countries may assist Annex B Parties in meeting their mitigation commitments via the Clean Development Mechanism (CDM), under the Protocol's Article 12.

Annex I countries under the UNFCCC, which include all Annex B countries under the Kyoto Protocol, are largely the wealthiest countries and largest historical emitters of GHGs. However, Annex I countries' share of historical cumulative GHG emissions in 2010 is close to the share of the non-Annex I countries (Section 13.13.1.1). Thus, the Kyoto Protocol's mitigation commitments were initially consistent with the UNFCCC principle of 'common but differentiated responsibilities and respective capabilities' (CBDRRC). However, since the UNFCCC divided countries into two categories in 1992, both income patterns and the distribution of GHG emissions have changed significantly, even as variations in income and per capita responsibility for emissions remain substantial both within and between countries. Between Conference of Parties (COP)-13 (Bali) in 2007 and COP-16 (Cancún) in 2010, many developing countries put forward quantifiable mitigation *actions* (as contrasted with quantified, economy-wide emissions reductions *targets* assumed by Annex B parties under the Kyoto Protocol) and agreed to more frequent reporting and enhanced transparency of those actions. Further pledges of actions have been made since Cancún. (Section 13.13)

For many developing countries, adaptation can have comparable priority to mitigation. This may be because countries are especially vulnerable to climate change damages or they lack confidence in progress with mitigation efforts. These countries are often the least able to finance adaptation, leaving cooperative agreements to attempt to identify sources of support. (See Chapter 16 for detail.)

International collaboration regarding public climate finance under the UNFCCC dates back to 1991, when the Climate Change Program of the Global Environment Facility (GEF) was established. The literature reflects mixed evidence on the scale and environmental effectiveness of such funding. Funding for reporting and mitigation flows through four primary vehicles: the GEF, which focuses on mitigation; the Least Developed Country Fund (LDCF) and Special Climate Change Fund (SCCF), created in 2001 for adaptation purposes and operated by the GEF; the Adaptation Fund set up in 2008; and the Green Climate Fund (GCF), established in 2010 for mitigation and adaptation. (Section 13.11, see also Section 16.2) The Copenhagen Accord set a goal to jointly mobilize 100 billion USD/yr by 2020 to address the needs of developing countries. (Section 13.11) Article 4.5 of the UNFCCC also calls for technology transfer from developed to developing countries. The Technology Mechanism, with an Executive Committee and Climate Technology Centre and Network, is seeking to fulfil this goal.

Research indicates that adaptation assistance, such as that provided by the Kyoto Protocol's Adaptation Fund, can be crucial for inclusion of developing countries in international climate agreements. Further research into the distribution of adaptation finance across countries from both UNFCCC and non-UNFCCC sources is required to assess the equity, efficiency, effectiveness, and environmental impacts of the Adaptation Fund and other funding mechanisms. Many developing countries have created institutions to coordinate adaptation finance from domestic and international funding sources. (Sections 13.3, 13.5)

The literature identifies several models for equitable burden sharing—among both developed and developing countries in international cooperation for climate change mitigation. The principles on which burden sharing arrangements may be based are described in Section 4.6.2, and the implications of these arrangements are discussed in Section 6.3.6.6. Distributional impacts from agreements will depend on the approach taken, criteria applied to operationalize equity, and the manner in which developing countries' emissions plans are financed; studies suggest potential approaches (Section 13.4, UNFCCC Secretariat 2007b, 2008). A major distributional issue is how to account for emissions from goods produced in a developing country, but consumed in an industrialized country. Such emissions have increased rapidly since 1990, as developed countries have typically been importers of embodied emissions, while many developing countries have large shares of emissions embodied in exports. (Sections 13.8, 14.3.4)

New and existing coalitions of countries have engaged in the UNFCCC negotiations, each presenting coordinated positions. Several distinct coalitions of developing countries have formed to negotiate their divergent priorities. Examples include the Group of 77 (G-77) and China, which contains sub-groups such as the African Group, the Least Developed Countries, and the Arab Group; the Alliance of Independent Latin American and Caribbean states; and a 'like-minded developing country' group that included China, India, and Saudi Arabia. Other coalitions organized to influence UNFCCC negotiations include the Alliance of Small Island States (AOSIS); various groupings of industrialized countries, including the Umbrella Group; the Environmental Integrity Group; the BASIC countries (Brazil, South Africa, India, and China); the Coalition of Rainforest Nations; and other active coalitions not limited to the climate context, for example, the Comision Centroamericana de Ambiente y Desarollo and the Bolivarian Alliance for the Americas.

13.2.2.5 Conflicts and complementarities

Criteria may be mutually reinforcing (Cao, 2010a; c), but there may also be conflicts, forcing tradeoffs between and among them. For example, maximizing global net benefits or attaining cost-effectiveness may lead to actions that decrease distributional equity (van Asselt and Gupta, 2009), which could lead to low participation. Posner and Weisbach (2010) and Baer (2009) argue that efficiency and distribution can be reconciled by either normatively adjusting the net benefit or cost calculations to account for changes in relative utility, or by adopting redistributive policy in addition to cost-effective climate policy.

Different approaches to meet the same criteria (for example, equity) may also conflict with each other when operationalized (Fischer and Morgenstern, 2010) or lead to different results (Dellink et al., 2009). Simultaneously, there are relations among sub-criteria: excessive flexibility may undermine incentives to invest in long-term solutions, and may also increase the likelihood of participation. Compromises to enable institutional feasibility of an agreement may weaken performance along other dimensions. The environmental performance of an international agreement depends largely on tradeoffs among the ambition of an agreement with regards to mitigation goals and participation, and compliance (Barrett, 2003; Bodansky, 2011a; Rajamani, 2012a). For further discussion of potential tradeoffs between participation and environmental effectiveness, see Section 13.3.3.

13.3 International agreements: Lessons for climate policy

Several lessons from research on existing international agreements, as well as game-theoretic models of such agreements, can be applied to climate change institutions. This section briefly summarizes some of the key lessons, which are addressed in more detail in subsequent sections of this chapter.

13.3.1 The landscape of climate agreements and institutions

Since the publication of IPCC AR4 in 2007, the landscape of international institutions related to climate policy has become significantly more complex. Climate change is addressed in a growing number of fora and institutions and across a wider range of scales (Keohane and Victor, 2011; Bulkeley et al., 2012; Biermann et al., 2009, 2010; Barrett, 2010; Abbott, 2011; Hoffmann, 2011; Zelli, 2011; Rayfuse and Scott, 2012).

Figure 13.1 illustrates the variety of international, transnational, regional, national, sub-national, and non-state agreements and other forms of cooperation, many of which have emerged since the mid-2000s. Some regimes that previously focused on other issues, e.g., trade (see Section 13.8), energy (see Chapter 7), biodiversity, and human rights have begun to address climate change. For a more detailed discussion of these initiatives, see also Section 13.5.

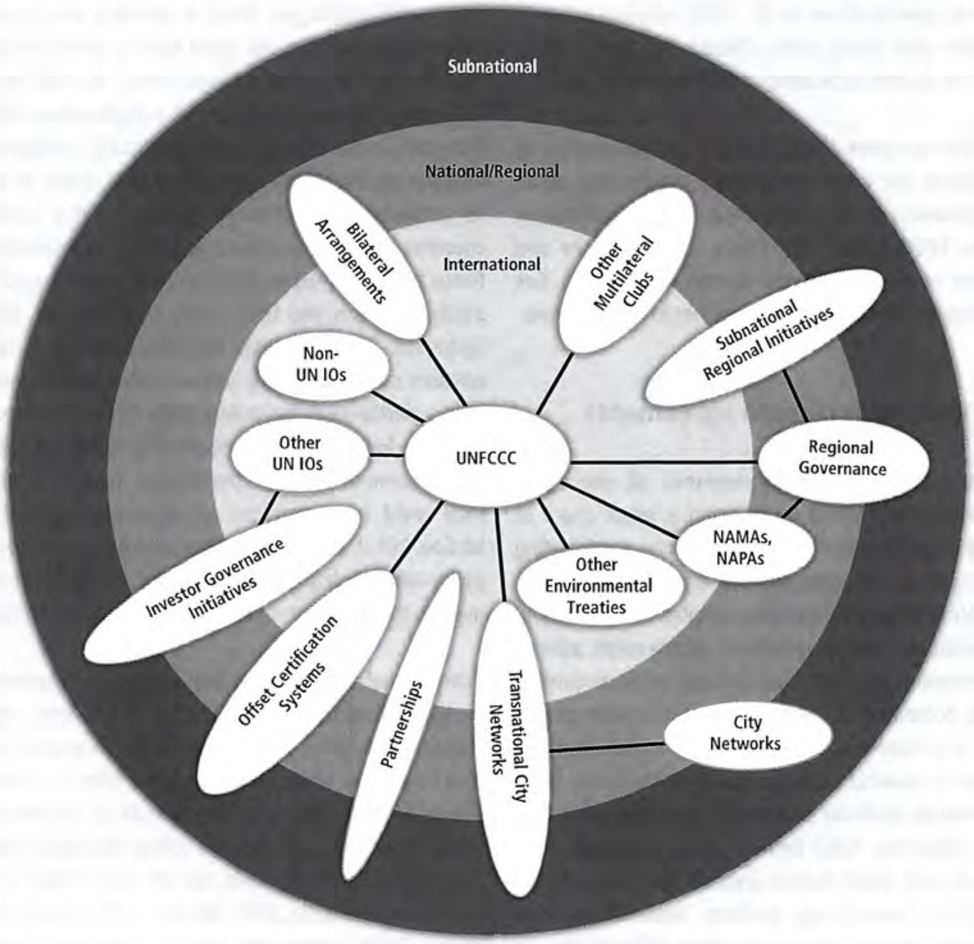
Future efforts for international cooperation on climate policy will need to account for this wide variety of agreements and institutions. Careful design of linkages and cooperative arrangements will be needed to manage the increasingly fragmented regime complex to prevent conflicts among institutions (Biermann et al., 2010; Keohane and Victor, 2011; Zelli, 2011), avoid gaps or loopholes (Downs, 2007), and maximize potential institutional synergies (Hoffmann, 2011; Rayfuse and Scott, 2012).

13.3.2 Insights from game theory for climate agreements

Game theory provides insights into international cooperation on climate policy, from research communities in environmental economics (Ward, 1993; Finus, 2001, 2003; Wagner, 2001; Barrett, 2003, 2007) and in the rationalist school of political science (Sjostedt, 1992; Downs et al., 1996; Underdal, 1998; Koremenos et al., 2001; Avenhaus and Zartman, 2007; Hafner-Burton et al., 2012). These researchers analyze the incentives and motivations of actors to join and comply with international environmental agreements (IEAs).

The game-theoretic literature on climate change agreements has grown substantially in the last two decades (Barrett, 2007; Rubio and Ulph, 2007; Chambers, 2008; Froyn and Hovi, 2008; Bosetti et al., 2009a; Asheim and Holtsmark, 2009; Dutta and Radner, 2009; Muñoz et al., 2009; Carbone et al., 2009; Weikard et al., 2010; Bréchet et al., 2011; Wood, 2011; Heitzig et al., 2011; Dietz and Zhao, 2011; Bréchet and Eyckmans, 2012; Pittel and Rübbelke, 2012). It is important, however, to treat with caution any general conclusions from recent game theory literature on climate change agreements, as many have been criticized for their simplicity. In this section, we refrain from listing assumptions in detail, and restrict attention to the most general and policy-relevant discussions. See Finus (2001, 2003) for a more detailed review of the relevant game theory literature.

By and large, the game-theoretic literature assumes actors to be states that are maximizing the welfare of their citizens (Ward, 1993; Carraro and Siniscalco, 1998; Grundig, 2006). A central premise is that there is currently no supranational institution that can impose an IEA on governments and subsequently enforce it (see Section 13.2.1.1). Thus, IEAs must be self-enforcing to engage and maintain participation and compliance (Finus, 2001; Barrett, 2007; Dutta and Radner, 2009; Rubio and Casino, 2005; Heitzig et al., 2011). Nevertheless, in theory and practice, international institutions can help to promote, negotiate, and administer an IEA. They can do so by serving to coordinate and moderate negotiations and implementation, reducing transaction costs



UNFCCC	Kyoto Protocol, Clean Development Mechanism, International Emissions Trading
Other UN Intergovernmental organizations	Intergovernmental Panel on Climate Change, UN Development Programme, UN Environment Programme, UN Global Compact, International Civil Aviation Organization, International Maritime Organization, UN Fund for International Partnerships
Non-UN IOs	World Bank, World Trade Organization
Other environmental treaties	Montreal Protocol, UN Conference on the Law of the Sea, Environmental Modification Treaty, Convention on Biological Diversity
Other multilateral 'clubs'	Major Economies Forum on Energy and Climate, G20, REDD+ Partnerships
Bilateral arrangements	e. g., US-India, Norway-Indonesia
Partnerships	Global Methane Initiative, Renewable Energy and Energy Efficiency Partnership, Climate Group
Offset certification systems	e. g., Gold Standard, Voluntary Carbon Standard
Investor governance initiatives	Carbon Disclosure Project, Investor Network on Climate Risk
Regional governance	e. g., EU climate change policy
Subnational regional initiatives	Regional Greenhouse Gas Initiative, California emissions-trading system
City networks	US Mayors' Agreement, Transition Towns
Transnational city networks	C40, Cities for Climate Protection, Climate Alliance, Asian Cities Climate Change Resilience Network
NAMAs, NAPAs	Nationally Appropriate Mitigation Actions (NAMAs) of developing countries; National Adaptation Programmes of Action (NAPAs)

Figure 13.1 | The landscape of agreements and institutions on climate change. Lines connecting different types of agreements and institutions indicate different types of links. In some cases, lines represent a formal agreement of a division of labour (e. g. between the UNFCCC and ICAO concerning aviation emissions). In other cases, lines represent a more simple mutual recognition (e. g. the accreditation of C40 cities by the UNFCCC). In others still, lines represent a functional linkage without any formal relationship (e. g. the relationship between the CDM and the NGO certification of carbon offsets). This is a rapidly-changing landscape and not all links may be captured.

of negotiations, and generating trust (Keohane, 1984, 1989; Finus and Rundshagen, 2006); changing the interests of actors by providing new information or building capacity (Haas et al., 1993); enlisting actors in domestic politics within and across states (Abbott and Snidal, 2010; Hafner-Burton et al., 2012); and inculcating norms (Bodansky, 2010a).

Alternative perspectives on game theory weaken the assumption of rationality and emphasize the roles of legitimacy, norms, and acculturation in shaping behaviour under international law and institutions (Goodman and Jinks, 2004; March and Olsen, 2008; Brunnée and Toope, 2010; Bernauer et al., 2010; Hafner-Burton et al., 2012). See Chapter 2 for a discussion of behavioural approaches in the literature.

13.3.3 Participation in climate agreements

Greater participation in climate change agreements, all else equal, improves environmental effectiveness by covering a larger share of global emissions and reducing potential leakage to non-participating areas. Greater participation may also improve aggregate economic performance by enabling lower-cost emissions abatement and reducing leakage. An international climate agreement regime might achieve depth (ambition of emissions reduction) and breadth (of participation) in different sequence. Schmalensee (1998) argues for breadth of participation first, with less emphasis on ambition. He argues that this approach allows time to develop correspondingly broad-based institutions that can potentially facilitate substantial aggregate emissions reductions over time (Schelling, 1992; Barrett, 2003). Conversely, pursuing an arrangement with depth before breadth can be motivated by the urgency of the climate-change problem. However, such an approach may make broadening participation more difficult later on (Schmalensee, 1998), and this type of agreement could induce emissions leakage, undermining effectiveness (Babiker, 2005).

In the theoretical literature, the tradeoff between the level of abatement by a sub-set of actors and participation in an IEA has been analyzed as a comparison between an 'ambitious versus a modest treaty' (Finus and Maus, 2008; Courtois and Haeringer, 2011) or between a focal (deep and narrow) versus a consensus (broad but shallow) treaty (Barrett, 2002; Hafner-Burton et al., 2012). Scholars conclude that, overall, a consensus treaty may achieve more in terms of emission reductions and global welfare than a focal treaty. Further analysis has investigated the tradeoff between breadth and depth, and how broad participation can increase environmental effectiveness (by covering more emissions and reducing leakage), and reduce costs (by encompassing more low-cost abatement options in a larger market). Through these plausible mechanisms, greater breadth enables greater ambition (subject to the costs of attracting participants) (Battaglini and Harstad, 2012).

While most existing IEAs feature open membership, some theoretical literature finds that exclusive membership can help to stabilize IEAs, prevent defection, and lead to better environmental outcomes, even in the context of a global public good such as climate protection (Carraro and Marchiori, 2003; Eyckmans and Finus, 2006; Finus, 2008a; Finus and Rundshagen, 2009). In practice, exclusive membership may reduce supply of a public good such as global emissions abatement, may increase emissions leakage (unless non-members are covered by their own coalition in a system of multiple agreements), and may conflict with norms of institutional legitimacy. Multiple agreements (i.e., multiple coalitions) may be a pragmatic, short- to mid-term strategy for achieving more effective cooperation if a universal treaty of all countries to limit emissions is not stable or attainable in the short-run (Finus and Rundshagen, 2003; Stewart and Wiener, 2003; Asheim et al., 2006; Eyckmans and Finus, 2006; Bosetti et al., 2009b; Bréchet and Eyckmans, 2012). Multiple coalition agreements involving all major emitters could potentially achieve better environmental effectiveness than a partial coalition acting while other countries do not act at all. However, for protecting a global public good, separate coalitions could forego some of the cost-effectiveness gains of a broader regime, and they could face questions of legitimacy (Karlsson-Vinkhuyzen and McGee, 2013). It remains unclear whether partial coalitions for climate policy will accelerate momentum for a more universal global agreement in the future, or undermine such momentum (Brewster, 2010).

International transfers can also attract participation in climate agreements, balancing the asymmetric gains from cooperation. These transfers can either be direct monetary transfers (e.g., contributions to a fund from which developing countries can draw), in-kind transfers (e.g., technology transfer), or indirect transfers via market-based mechanisms (e.g., through the initial allocation of tradable emission permits) (Carraro et al., 2006; Barrett, 2007; Bosetti et al., 2009a; Fuentes-Albero and Rubio, 2010; Bréchet and Eyckmans, 2012; Stewart and Wiener, 2003). Historically, transfers have been important for building participation in past international agreements (Hafner-Burton et al., 2012; Bernauer et al., 2013). The experience of the Montreal Protocol illustrates how transfers can engage participation by major developing countries through financial and technological assistance (Sandler, 2010; Kaniaru, 2007; Zhao, 2005, 2002; Andersen et al., 2007). The role of technology transfer in international cooperation is discussed in greater detail in Section 13.9, and the role of finance is discussed in Section 13.11.

Linkages across issues may also help encourage participation. Many linkages exist between climate change and other issues, such as energy, water, agriculture, sustainable development, poverty alleviation, public health, international trade, human rights, foreign direct investment, biodiversity, and national security (see Sections 3.4, 5.7, 6.6, and Section 13.2.1.1). Such linkages may create opportunities, co-benefits, or adverse side-effects, not all of which have been thoroughly examined. However, the advantages of issue linkage may diminish as the number of parties and issues increase, raising the transaction costs of negotiations (Weischer et al., 2012).

A different instrument to encourage participation is trade sanctions against non-parties to an IEA. The threat of trade sanctions can motivate participation (Barrett, 2003; Victor, 2011), as exemplified by the Montreal Protocol. However, since participation in an international treaty is voluntary, sanctions for non-participation may be difficult to justify (see Section 13.3.4). Similar to trade sanctions are 'offsetting border adjustment measures' (BAMs) (see Section 13.8 for further discussion).

Particularly vulnerable countries may be more likely to participate in agreements that address and fund adaptation activities (Huq et al., 2004; Mace, 2005; Ayers and Huq, 2009; Denton, 2010; Smith et al., 2011). Benefits of adaptation are often local, and these local benefits may be more effective incentives for countries vulnerable to climate damages to participate in an IEA relative to the benefits of mitigation and support for technological development or deployment. Both of these alternative possible incentive mechanisms are less-excludable and are of potentially less value to lower-emitting countries, compared with adaptation benefits. Recent game theoretic analyses suggest that private co-benefits from mitigation actions may not substantially increase participation in international climate agreements (Pittel and Rübbelke, 2008; Finus and Rübbelke, 2012).

A final key issue related to participation is the role played by uncertainty. Earlier research suggested that reducing uncertainty about the benefits and costs of mitigation can render IEAs less effective, showing that as parties learn of the actual costs and benefits of mitigation, their incentive to participate may shrink (Na and Shin, 1998; Kolstad, 2005; Kolstad and Ulph, 2008). However, more recent work (Finus and Pintassilgo, 2012, 2013; Dellink and Finus, 2012) has qualified this conclusion by showing that removing uncertainty only has a negative impact on cooperation in certain cases. Recent experimental evidence suggests that if there is uncertainty in the likelihood of tipping points of disastrous climate change impacts, this may reduce the success of cooperation (Dannenberg et al., 2011); conversely, reducing uncertainty about the likelihood of tipping points can increase prospects for collective action (Barrett and Dannenberg, 2012).

13.3.4 Compliance

As noted in Section 13.2.1.1, in the absence of a supranational authority, compliance with international agreements must be verified by parties to the agreement or through a related collaborative body they perceive as legitimate. Barrett (2003) sees compliance as a dimension of participation, in the sense that incentives to comply are incentives to continue participating in the agreement. The reputational costs of being a non-compliant party may differ from those of withdrawing altogether, but the magnitude of the difference is not clear. For example, there is only one case of withdrawal from the Kyoto Protocol, that of Canada in December 2011, but more than one case in which countries have not met their agreed emission targets (see Section 13.13.1.1).

Compliance does not necessarily equate with success—because countries choose whether to become party to an agreement, compliance may only reflect what countries would have done without the agreement (Downs et al., 1996). One measure of effectiveness is the extent to which the agreement changed countries' behaviour, compared to what they would have done in the absence of the agreement (the counterfactual baseline scenario) (Hafner-Burton et al., 2012). Evaluating an agreement's effectiveness is difficult because the counterfactual is not observed (Simmons and Hopkins, 2005; Mitchell, 2008; Hafner-Burton et al., 2012).

A necessary condition for successful compliance strategies is an independent and effective regime of 'measurement (or monitoring), reporting, and verification' (MRV) with a high frequency of reporting (as documented in the IPCC TAR; see also Section 2.6.4.3). Provisions for greater transparency in MRV are being developed with regard to (1) countries' GHG emissions, and (2) international financial flows from developed countries to developing countries for mitigation and adaptation measures (Winkler, 2008; Breidenich and Bodansky, 2009; Ellis and Larsen, 2008; Ellis and Moarif, 2009; Clapp et al., 2012). Lessons on MRV from other multilateral regimes—such as International Monetary Fund (IMF) consultations, Organisation for Economic Co-operation and Development (OECD) economic policy reviews, World Trade Organization (WTO) trade policy reviews, and arms control agreements—include attention to accuracy, evolution over time, combining self-reporting with third-party verification, including independent technical assessment as well as some form of political or peer review, the potential use of remote sensing or other technical means, and public domain outputs (Cecys, 2010; Pew Center, 2010; Bell et al., 2012).

Technical capabilities for monitoring emissions now include remote sensing from satellites which themselves pose new issues about the availability, diffusion, and governance of MRV capabilities for greater transparency. Greater transparency about financial flows requires detailed analysis of donor government budgeting in their legislative and administrative processes (Clapp et al., 2012; Falconer et al., 2012; Brewer and Mehling, 2014).

Measurement, reporting, and verification may be beneficially complemented by enforcement strategies, which are comprised of positive inducements—such as international transfers, financing, capacity-building, and technology transfer—and credible threats of sanctions for violating emissions commitments or reporting requirements. From a rationalist perspective, compliance will occur if the discounted net benefits from cooperation (including direct climate benefits, co-benefits, reputation, transfers, and other elements) exceed the discounted net benefits of defection (including avoided mitigation costs, avoided adverse side-effects, and expected sanctions). The institutional and behavioural reality of ensuring compliance can be more complicated. Moreover, the theoretical literature has stressed the difficulty of designing credible sanctions that are renegotiation-proof (Finus, 2001, 2003; Barrett, 2002; Asheim et al., 2006; Froyn and Hovi, 2008).

Some research suggests that the Kyoto Protocol is unusual among IEAs in that it established an 'elaborate and multifaceted' compliance system, which has been successful in assuring compliance with MRV requirements (Finus, 2008b; Oberthür and Lefeber, 2010; Brunnée et al., 2012), while many other IEAs rely on self-reporting of domestic actions. Compliance with MRV requirements can in turn improve detection of other forms of noncompliance. Even if the Kyoto Protocol compliance regime has been imperfect, it can offer lessons for future regimes, in particular with regard to MRV. The design of sanction mechanisms currently in place under the Kyoto Protocol, however, has also been criticized for not being fully credible (Halvorssen and Hovi, 2006; Barrett, 2009; Vezirgiannidou, 2009), though possibilities for improvement through modification have been identified (Finus, 2008b). For example, a sanction could take the form of a temporary suspension of monetary and technological transfers if recipient countries are found in non-compliance (Finus, 2008b). It has also been shown that a deposit system can be effective to enforce compliance: treaty members lodge a deposit into a fund from which they receive interest as long as they comply. In case of non-compliance, parts of the deposit are forfeited to compliant countries (Gerber and Wichardt, 2009, 2013).

Trade sanctions, such as those employed under the Montreal Protocol, are frequently put forward as a possible compliance mechanism (Barrett, 2003; Victor, 2011) (see Section 13.8 for institutional details and further discussion). A general reservation about trade sanctions is that they often not only affect the agreement-violator but also compliant countries, and hence this threat is not credible. Barrett (2009), Victor (2010), and others argue that trade sanctions are neither a feasible nor a desirable option for enforcing compliance with a climate agreement because trade sanctions may not be compatible with WTO rules. A WTO-compatible design may be feasible in the case of border adjustments with obligations to buy allowances (Ismer and Neuhoff, 2007; Monjon and Quirion, 2011). Meanwhile, imposition of trade sanctions would pose some risks of reducing cooperation by undermining capacity for compliance in targeted countries and could be burdensome to low-income populations in targeted countries (Murase, 2011). Especially if applied to embedded carbon (carbon from energy used to produce traded goods), the number of goods affected by the sanctions could be large, potentially fuelling a trade war that may negatively affect even those countries that intend to be the punishers (McKibbin and Wilcoxen, 2009) (see Sections 13.8 and 5.4.1 for further discussion).

Finally, there is a considerable literature on the potential use of legal remedies (such as civil liability) to address climate damages (Penalver, 1998; Grossman, 2003; Allen, 2003; Gillespie, 2004; Hancock, 2004; Burns, 2004; Verheyen, 2005; Jacobs, 2005; Smith and Shearman, 2006; Lord et al., 2011; Farber, 2011; Faure and Peeters, 2011). There has been little suggestion that such liability remedies be formally incorporated into climate agreements as compliance mechanisms, and there would be significant obstacles to doing so (including the lack of a robust international civil liability system). Nonetheless, this is a potential avenue for encouraging compliance, perhaps indirectly. The IPCC AR4 (IPCC, 2007) reported on evidence from various legal actions and potential actions that have been considered in the theoretical literature. Haritz (2011) has argued, based on an analysis of the literature and court cases, that it is theoretically possible to link the IPCC scale of likelihood with a scale based on legal standards of proof required for various kinds of legal action. Liability for climate change damage at the supranational level (de Larragán, 2011; Gouritin, 2011; Peeters, 2011), and at the national level in the United Kingdom (Kaminskaite-Slaters, 2011), the United States (Kosolapova, 2011), and the Netherlands (van Dijk, 2011), has been explored. Climate litigation and legal liability may put additional pressure on corporations and governments to be more accountable (Smith and Shearman, 2006; Faure and Peeters, 2011). However, there are key analytical hurdles to establishing important legal facts, such as causation and who is to be held liable (Gupta, 2014). While not framed in terms of liability or compensation, the UNFCCC negotiations in Doha decided to establish institutional arrangements associated with Loss and Damage (UNFCCC, 2013a).

13.4 Climate policy architectures

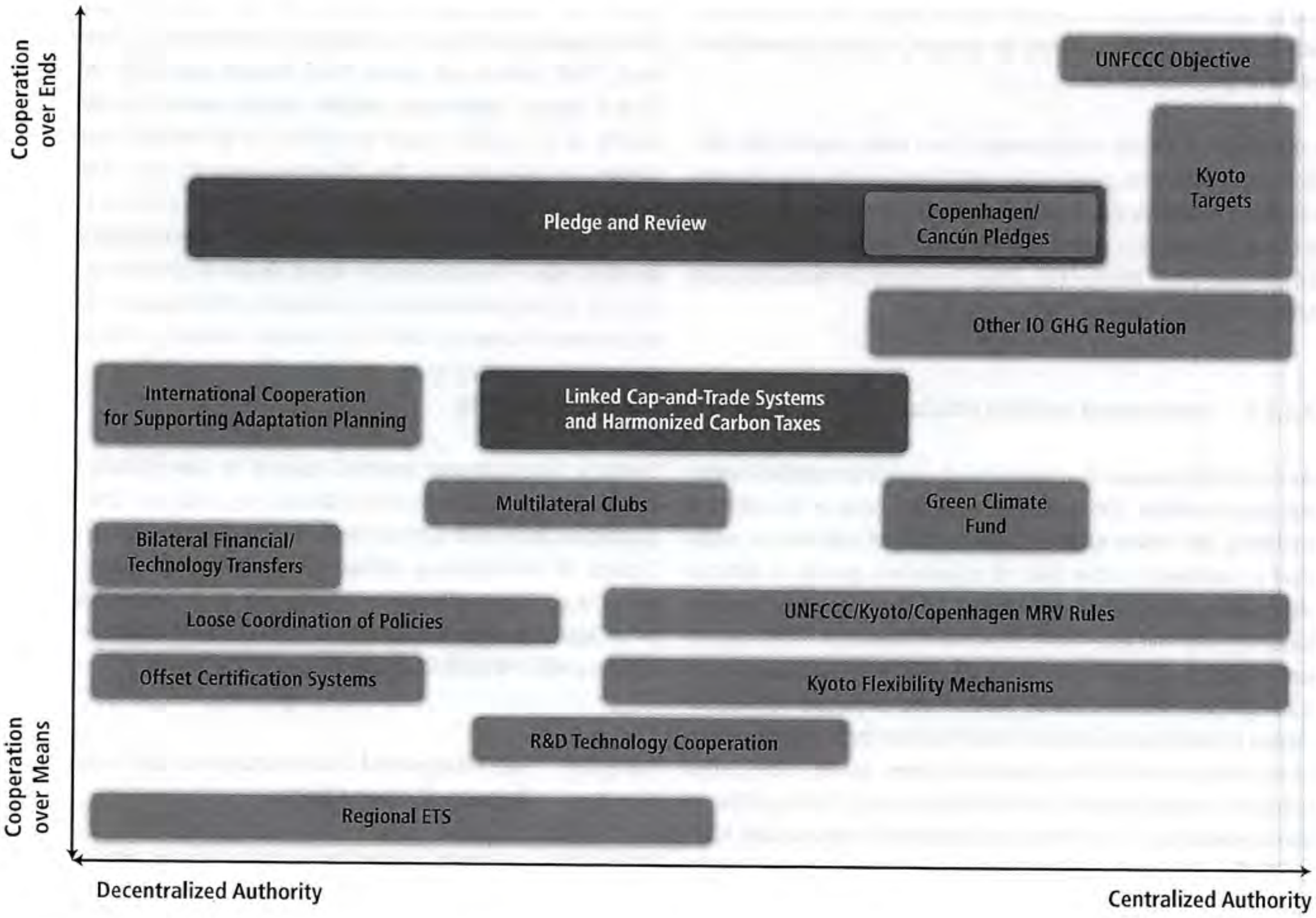
'Policy architecture' for global climate change refers to "the basic nature and structure of an international agreement or other multilateral (or bilateral) climate regime" (Aldy and Stavins, 2010a). The term includes the sense of durability, with regard to both policy structure and the institutions to implement and support that structure (Schmalensee, 1998, 2010), which is appropriate to the long-term nature of the climate-change problem.

13.4.1 Degrees of centralized authority

Absent the emergence of a global authority that has the capacity to impose an allocation of emissions rights on countries, as advocated by Tickell (2008), approaches to international cooperation all arise out of negotiated agreements among independent participants. However, they vary in the degree to which they confer authority on multilateral institutions to manage the rules and processes agreed to. On one end of the spectrum of possible approaches, referred to by some as 'top-down' (Dubash and Rajamani, 2010), actors agree to a high degree of mutual coordination of their actions with, for example, fixed targets and a common set of rules for specific mechanisms, such as emissions trading. On the other end of the spectrum, sometimes known as 'bottom-up' (Victor et al., 2005; Dubash and Rajamani, 2010), national policies are established that may or may not be linked with one another.

Figure 13.2 illustrates how existing and proposed international agreements can be placed on this spectrum (see IPCC, 2007, pp. 770–773 for a detailed list of many proposals that could be placed in this grid). The level of centralization refers to the authority an agreement confers on an international institution, not the process of negotiating the agreement. It shows that many proposals can be more or less centralized depending on the specific design. It also shows that the three idealized types discussed in the following sections have more blurred boundaries than their titles suggest. The figure also divides them into agreements focused on specific ends (emissions targets, for example)—and those that focus on means (specific policies, or technologies, for example). Finally, it should be understood that these are idealized types, and in practice there will be considerable additional complexity in how the basic design of agreements connect the actions of the various actors that make them up. There are distinct limits to what can be gleaned from the 'top-down vs bottom-up' metaphor or the degrees-of-centralization notion employed here (Dai, 2010) as, for example, emphasized in Ostrom's (2012) accounts of 'polycentric governance'.

As one prominent example, the Cancún Agreements are a 'hybrid' of top-down and bottom-up. They include voluntary mitigation pledges from many (but not all) UNFCCC parties, together with additional or elaborated common goals and centralized UNFCCC functions (e.g., with regard to adaptation, see Part II of the Cancún Agreements (UNFCCC, 2010)). It is quite possible that the agreement mandated by the Durban Platform on Enhanced Action, to be completed by 2015, will also be such a hybrid.



Loose coordination of policies: examples include transnational city networks and Nationally Appropriate Mitigation Actions (NAMAs);
R&D technology cooperation: examples include the Major Economies Forum on Energy and Climate (MEF), Global Methane Initiative (GMI), or Renewable Energy and Energy Efficiency Partnership (REEEP); Other international organization (IO) GHG regulation:
examples include the Montreal Protocol, International Civil Aviation Organization (ICAO), International Maritime Organization (IMO).

Figure 13.2 | Alternative forms of international cooperation. The figure represents a compilation of existing and possible forms of international cooperation, based upon a survey of published research, but is not intended to be exhaustive of existing or potential policy architectures, nor is it intended to be prescriptive. Examples in orange are existing agreements. Examples in blue are structures for agreements proposed in the literature. The width of individual boxes indicates the range of possible degrees of centralization for a particular agreement. The degree of centralization indicates the authority an agreement confers on an international institution, not the process of negotiating the agreement.

13.4.1.1 Centralized architectures and strong multilateralism

A centralized architecture, such as that generated by strong commitments to multilateral processes and institutions, is an agreement that establishes goals, targets, or both which are generally binding, for participating countries, within a specific time-frame, and establishes collective processes for monitoring progress towards meeting those goals. The Kyoto Protocol adopted targets and timetables for participating Annex B countries, one realisation of strong multilateralism (Bodansky, 2007). Other centralized approaches to international cooperation could expand on targets-and-timetables by also specifying the mechanism for implementation of the goals and/or targets of the agreement. Such an approach could establish, for example, a global cap-and-trade system or global carbon tax.

In the literature, targets-and-timetables have been coupled with specific notions of fairness, prospective conditions for political acceptance, or both—to establish quantitative targets and timetables for all countries and all years in a potential international agreement (Agarwala, 2010; Frankel, 2010; Höhne et al., 2008; Bosetti and Frankel, 2011; Cao, 2010c; IPCC, 2007, Chapter 13).

13.4.1.2 Harmonized national policies

A less-centralized approach would be to structure international cooperation around policies that would be harmonized, such as via collective monitoring, but where relatively little centralized authority is established or employed. In this class of approaches, aspects of national policies are made similar or even equivalent to one another. Examples include the G20 and Asia-Pacific Economic Cooperation (APEC) agreement in 2009 to phase out fossil fuel subsidies that encourage wasteful consumption (Barbier, 2010); the EU's use of private certification schemes for biofuels to link to its import policies for such fuels; efforts to harmonize private carbon-accounting systems, such as in the Carbon Disclosure Standards Board (Lovell and MacKenzie, 2011); hypothetical national carbon taxes that would be harmonized internationally (Cooper, 2010); adjusting design details of cap-and-trade schemes that are to be linked; and implementation of similar technology or performance standards. Many of these involve—or would involve—relatively limited numbers of actors, compared to UNFCCC agreements, reflecting the 'minilateralism' discussed in Section 13.2.1.1.

The so-called 'pledge and review' approach, exemplified to some degree by the Copenhagen Accord and the Cancún Agreements, is an architecture in which a participating nation or region voluntarily registers to abide by its stated domestic reduction targets or actions (pledges). The degree of centralization generated by this approach could vary considerably (see Figure 13.2), depending on the particular arrangement. If a pledge and review system, such as that represented by the Cancún Agreements, involved cooperation in forging an agreement that provided some centralized administration or monitoring (in addition to the voluntary announcement of pledges by individual countries), it could be considered an example of strong multilateralism, although perhaps with less centralized authority than the Kyoto Protocol or of coordinated national policies.

13.4.1.3 Decentralized approaches and coordinated policies

Finally, even more decentralized architectures may arise out of different regional, national, and sub-national policies, and subsequently vary in the extent to which they are connected internationally (Victor et al., 2005; Hoffmann, 2011). One form of decentralized architecture is linked regional, national, or sub-national tradable permit systems (Jaffe et al., 2009; Ranson and Stavins, 2012; Mehling and Haites, 2009). In such a system, smaller-scale tradable permit systems can be linked directly (e.g., through mutual recognition of the permits from other systems) or indirectly (e.g., through mutual recognition of an emission reduction credit system such as the Kyoto Protocol's CDM). In practice, such a system of linkage is already emerging. However, there remains the challenge of harmonizing the design details of the various trading systems, as discussed above (e.g., emissions reductions requirements, proportions of target emissions that may be covered by offset credits, use of ceiling or floor prices, and accounting units (Jaffe et al., 2009; Bernstein et al., 2010).

Similarly, heterogeneous regional, national, or sub-national policies could be linked either directly or indirectly (e.g., cap and trade in one jurisdiction linked with a tax in another) (Metcalf and Weisbach, 2012). Linkage of heterogeneous policies can occur through trade mechanisms (e.g., import allowance requirements or border adjustments) or via access to a common emission reduction credit system (e.g., the CDM, as with indirectly linked tradable permit systems).

13.4.1.4 Advantages and disadvantages of different degrees of centralization

Some authors conclude, particularly post-Copenhagen, that attempts to develop a comprehensive, integrated climate regime have failed, due to resistance to costly policies in both developed and developing countries and lack of political will (Michonski and Levi, 2010; Keohane and Victor, 2011), or alternatively because of the complexity that characterizes the problem (Hoffmann, 2011). Other analyses emphasize the legitimacy of the UN, particularly citing its universal membership (Hare et al., 2010; Winkler and Beaumont, 2010; Müller, 2010; La Viña, 2010) and noting that fragmentation of the climate regime could create opportunities for forum shopping, a loss of transparency, and reduced ambition (Biermann et al., 2009; Hare et al., 2010; Biermann, 2010). Other studies have examined (1) the evolution of multilateralism (Bodansky and Diringer, 2010) and possible transitional arrangements from fragmentation to a comprehensive agreement (Winkler and Vorster, 2007), and (2) how to manage fragmentation so that it may become synergistic rather than prone to conflict (Biermann et al., 2009; Oberthür, 2009).

13.4.2 Current features, issues, and elements of international cooperation

The policy architecture for climate change raises a number of specific questions about the structure of international cooperation. Four specific elements are of particular contemporary relevance: legal bindingness; goals, actions, and metrics; flexibility mechanisms; and participation, equity, and effort-sharing methods. These four elements deal with the key questions of how much an agreement insists on compliance with its obligations, what obligations it establishes, how flexible the implementation of the obligations may be, and how the obligations may vary across actors and situations. The discussion below focuses on mitigation of GHG emissions, but the four key elements apply as well to adaptation, financing, and other potential topics of international agreements on climate change. For example, UNFCCC Article 4(1)(b) (UNFCCC, 1992) calls on "all parties" to formulate and implement both "measures to mitigate climate change" by reducing net GHG emissions, and "measures to facilitate adequate adaptation to climate change." Understanding what is meant by such obligations requires examining these four key elements.

13.4.2.1 Legal bindingness

States choose whether to join an agreement, and can withdraw from an agreement, so international agreements exist by consent of the parties (Waltz, 1979; Thompson, 2006). Having said this, international agreements among states (national governments) may be more or less 'legally binding' on their parties. The degree of 'bindingness' depends on both the legal form of the agreement and the costs to the state of noncompliance.

Among the indicators of legal bindingness in the agreement itself are (1) legal type (e.g., treaty, protocol to a treaty, decision of the UNFCCC Conference of the Parties, and political declaration); (2) mandatory commitments, i.e., whether a commitment is 'expressed in obligatory language' (e.g., 'shall' or 'must,' vs. 'should' or 'aim') (Werksman, 2010)(Werksman, 2010)(Werksman, 2010); (3) specificity, i.e., "... whether [commitments] are expressed in sufficient detail to accurately assess compliance"; and (4) the type of enforcement procedures, mechanisms, and sanctions designed to implement an agreement by monitoring, reviewing, and encouraging compliance with commitments (Werksman, 2010).

International agreements may be labelled 'hard law' (such as treaties, their protocols, and contracts) that are legally binding on the

Table 13.1 | Taxonomy of legal bindingness: examples of commitments in international agreements for climate change.

Legal character (noting relevance of indicators 1–4 discussed in the text)	Description	Example
Mandatory provision in a legally binding agreement with enforcement mechanisms. (1)–(4)	A legally binding commitment can be subject to a compliance regime, with authority to sanction non-compliant parties. Enforcement can also come in the form of reciprocity for non-compliant actions.	The targets and timetables in the Kyoto Protocol (UNFCCC, 1998) and the Marrakech Accords (UNFCCC, 2001), with specific quantitative emissions limits, a compliance system that sanctions non-compliance, and flexibility mechanisms. (Outside the climate arena, the World Trade Organization is the most prominent example of this type.)
Mandatory provision in a legally binding agreement without enforcement mechanism. (1) and (2); possibly (3); but not (4)	'Legally binding,' but subject only to self-enforcement.	Article 4.1 of the UNFCCC (1992), mandating, *inter alia*, national emissions inventories, measures to mitigate, and measures to facilitate adaptation.
Non-mandatory provision in a legally binding agreement. (1), but not (2)–(4)	Such a provision does not demand compliance, but carries somewhat more weight than a political agreement.	Article 4.2 (a) and (b) of the UNFCCC (1992) commit developed countries to adopt policies and measures to limit their net GHG emissions (a mandatory provision); 4.2(a) then 'recognizes' that returning these emissions to earlier levels by the year 2000 would be desirable, and 4.2(b) provides the 'aim' of returning to 1990 levels (both non-mandatory provisions).
Mandatory provision in a non-legally binding ('political') agreement. (2), possibly (3); but not (1) or (4)	Such a provision may induce the party to act, through norms, reputation, and reciprocity.	The pledges on targets and actions submitted by states pursuant to the Copenhagen Accord (UNFCCC, 2009a) and Cancún Agreements (UNFCCC, 2010). (Outside the climate arena, the moratorium on high seas driftnet fishing is treated as binding by many states, even though United Nations General Assembly (UNGA) resolutions are not binding.)
Non-mandatory provision in a non-legally binding ('political') agreement. None of (1)–(4)	An aim or aspiration, expressed in hortatory, non-binding language. This type of provision typically includes one or more statements of principles or norms.	Targets set in the Noordwijk Declaration (1989), at a ministerial conference on climate change held prior to the 1992 Rio summit.

parties, or 'soft law' (such as declarations, resolutions, and guidelines) that are not legally binding. But the reality is more complex (Baxter, 1980; Abbott et al., 2000; Bodansky, 2010a; Guzman and Meyer, 2010). Across types of agreements, commitments may be more or less legally binding; for example, although treaties often contain mandatory commitments, a treaty may also contain hortatory provisions, such as aims and pledges, which are understood to be aspirational; while a political declaration may nonetheless contain provisions that raise strong expectations and consequences for failure (Raustiala, 2005). Some commitments may be specific and subject to monitoring and accountability, while others are vague and difficult to verify (Abbott and Snidal, 2000). Further, across types of agreements, the enforcement mechanism may be weak or rigorous, ranging from inaction to admonishments to trade sanctions to military force.

The bindingness of an agreement depends on the costs to a state of nonparticipation, noncompliance, or withdrawal—as well as to legal form. These costs include, as discussed above (see Section 13.3.4), not only the costs of sanctions imposed by the agreement's enforcement mechanism, but also the costs incurred from the state's loss of reputation and from the loss of mutual cooperation by other states. Reputational costs and lost-cooperation costs can influence states to adhere to (initially informal) norms; hence strong norms with high costs of violation are sometimes called 'binding' (Hoffmann, 2005, 2011; MacLeod, 2010).

Table 13.1 provides a taxonomy of the bindingness of international agreements (Bodansky, 2003, 2009). The usage of 'mandatory' in the table refers to the specific wording of the commitment—not to a state's choice of whether to participate or not.

Research has not resolved whether or under what circumstances a more binding agreement elicits more effective national policy. In general, a more legally binding commitment is more subject to monitoring and enforcement (both internationally and domestically), is more likely to require ratification by domestic institutions, and signals a greater seriousness by states (Bodansky, 2003; Rajamani, 2009). These factors increase the costs of violation (through enforcement and sanctions at international and domestic scales, the loss of mutual cooperation by others, and the loss of reputation and credibility in future negotiations).

On the other hand, there may be situations where there is a tradeoff between legal bindingness and ambition (stringency of commitments). Because greater legal bindingness implies greater costs of violation, states may prefer more legally binding agreements to embody less ambitious commitments, and may be willing to accept more ambitious commitments when they are less legally binding. (Rajamani, 2009; Raustiala, 2005; Guzman and Meyer, 2010; Albin, 2001; Grasso and Sacchi, 2011; Bodansky, 1999; Bernstein, 2005; See also Sections 13.2.2.5 and 13.3.3)

13.4.2.2 Goals and targets

Most agreements that advance international cooperation to address climate change incorporate goals. 'Goals' are 'long-term and systemic' (as contrasted with absolute emissions-reduction 'targets,' which may flow logically from the goals but which are 'near-term and specific') (IPCC, 2007, Chapter 13). The goals of an international agreement might include, for example, stabilization levels (or a reduction in a previously agreed stabilization level) of atmospheric concentrations of GHGs—or reductions in impacts of climate change.

Targets can be classified according to whether they require absolute GHG cuts relative to a historical baseline, or reductions relative to economic output, population growth, or business-as-usual projections (intensity targets). In recent literature on targets' metrics, there has been a focus on whether or not intensity targets are superior to fixed ones when there is uncertainty about the future (Jotzo and Pezzey, 2007; Marschinski and Edenhofer, 2010; Sue Wing et al., 2009; Conte Grand, 2013). There are tradeoffs between reduced uncertainty about the cost of abatement, associated with intensity targets, and reduced uncertainty about environmental effectiveness, associated with absolute targets (Ellerman and Wing, 2003; Herzog, Timothy et al., 2006).

In the UNFCCC climate negotiations, examples of fixed targets are Kyoto Annex B country-emission reductions by 2008–2012 with respect to 1990 levels, and Copenhagen pledges (Some of the developed countries propose emissions reductions by 2020 with respect to some base year—1990, 2000, or 2005—while some of the developing economies suggest reductions by 2020 with respect to their business-as-usual trends). On the other hand, intensity targets have been proposed by China and India: their pledge is a reduction of carbon intensity (i.e., emissions/gross domestic product (GDP)) between 40 and 45 % and 20 and 25 % respectively by 2020 with respect to 2005 (Steckel et al., 2011; Zhang, 2011; Yuan et al., 2012; Cao, 2010b; Government of India, 2012). Another carbon target linked to GDP was the one planned by Argentina in 1999 (Barros and Conte Grand, 2002).

13.4.2.3 Flexible mechanisms

One focus of international negotiations has been enabling states to have flexibility in meeting obligations. In principle, there are numerous ways this could be achieved. For example, there could be provisions for renegotiating targets. The most often-cited benefit of flexibility is reduction in the costs associated with GHG-emissions reductions. However, Hafner-Burton et al. (2012) explore whether increased flexibility in designing obligations for states helps them align their international obligations more readily with domestic political constraints.

In existing interstate agreements, flexibility has been pursued principally through mechanisms that create markets. The rationale for these is to lower the cost of reducing emissions, relative to traditional regulatory regimes, as they direct investments in emissions reductions toward lower-cost abatement opportunities available in various jurisdictions. Such flexible mechanisms can involve trading emissions allowances under a fixed overall cap, generating offset credits, or combinations of the two. Generally, offset credits can be generated through project-based mechanisms or crediting of policies and sectoral actions. The former have been developed since the mid-1990s, with the CDM as by far the largest programme (Michaelowa and Buen, 2012); the literature assessing the CDM is reviewed in Section 13.13.1.1.) The latter are still being discussed with regards to post-2012 climate policies in the context of 'new market mechanisms' related to mitigation policies in developing countries (Nationally Appropriate Mitigation Actions (NAMAs)). Additionally, inter-temporal flexibility may be added to an allowance-trading regime through banking and borrowing of allowances, by which regulated entities may transfer current obligations to the future or vice versa. However, the environmental effectiveness and distributional impact of carbon markets have also raised concerns (Lohmann, 2008; Böhm and Dabhi, 2009).

The Kyoto Protocol provides three flexible mechanisms: Joint Implementation (JI), the CDM, and international emissions trading (IET) (in Articles 6, 12, and 17, respectively). Joint Implementation and CDM both generate offset credits from projects that reduce GHG emissions, and IET allows for government-to-government trading of Kyoto emissions allowances. Most attention in the research on these mechanisms has focused on the CDM, in part because of the volume of trading compared to the others (on the relatively small volume in Kyoto emissions trading, see Aldrich and Koerner, 2012).

The credits from JI and CDM may be used by Annex B countries to meet their emissions-reduction obligations. In practice, the key driver of investment in CDM projects has been the European Union (EU) Emission Trading Scheme (ETS), which allows regulated entities (companies or installations) to use credits from the CDM (referred to as 'Certified Emission Reductions' (CERs) and from JI (referred to as 'Emissions Reduction Units' or ERUs) to meet a portion of their ETS obligations (see Sections 13.6.1 and 14.4.2.1 for details). The EU ETS has accounted for about 84 % of demand for CERs and ERUs from 2008–2012. The next largest source of demand for CERs and ERUs comes from Japan, at 15 % of demand (Kossoy and Guigon, 2012).

Market-based flexibility mechanisms are evolving. Japan is pursuing bilateral crediting approaches under its Joint Crediting Mechanism/Bilateral Offset Crediting Mechanism (Ministry of the Environment, Government of Japan, 2012). COP-17 in Durban in 2011 mandated two approaches be pursued in the UNFCCC negotiations leading to a new international agreement in late 2015: (1) top-down, operating under authority of the COP ('new market-based mechanism'), which, as noted, focuses in large part on sectoral crediting; and (2) bottom-up, developed by countries 'in accordance with their national circumstances' ('framework for various approaches'), which attempts to coordinate heterogeneous policies across countries. COP-18 in Doha, Qatar, in 2012 reiterated and developed further details regarding these two approaches (UNFCCC, 2013b).

13.4.2.4 Equitable methods for effort sharing

While universal participation might be desirable in principle, actors participate in a context of heterogeneity in both economic capacity and emissions levels. Variations in both wealth and emissions have evolved over time; for example, many countries classified in the 1992 UNFCCC as developing (non-Annex I) have since experienced increasing incomes and increasing emissions (in some cases exceeding the incomes and/or emissions of some countries classified in 1992 as developed (Annex I)). These variations and continued differences are discussed further in Section 4.1.2.2. As to participation in international agreements, in general, a country is less likely to participate in an international agreement the more the country perceives the agreement to be unfair to its own economic and environmental interests. Addressing climate change equitably can thus be central to pursuing broad participation in climate agreements.

There is disagreement, however, about how to put equity principles into practice in international agreements. The UNFCCC adopted the principle of CBDRRC of parties (Article 3.1) (UNFCCC, 1992). Several different approaches have been advanced for putting this principle into practice. Deleiul (2012) argues that CBDRRC initially facilitated agreement and participation in the UNFCCC, but has become more contentious as national variations in income and emissions have evolved over time (hence Deleiul sees promise in the Durban Platform, which calls for mitigation contributions from all parties in a new treaty concluded by 2015, to take effect by 2020).

Section 4.6.2 elaborates these different approaches in detail, and suggests they can be broadly divided into those that start with the status quo of emissions, that thus focus on the question of 'effort-sharing' or 'burden sharing,' and those that start with a specific account of 'rights' to GHG emissions (such as equal per capita or equal per GDP emissions) and derive targets for countries from that formula (known as 'resource-sharing'). Rao (2011) refers to these as burden sharing vs. resource-sharing equity principles. Burden sharing methods are reviewed in (Jotzo and Pezzey, 2007; den Elzen and Höhne, 2008, 2010; Winkler et al., 2009; Chakravarty et al., 2009; Mearns and Norton, 2010; Frankel, 2010; Ekholm et al., 2010; Marschinski and Edenhofer, 2010; Cao, 2010c; Tavoni et al., 2013; den Elzen et al., 2013b; Höhne et al., 2013). 'Resource-sharing' approaches are examined in (Höhne et al., 2006; Chakravarty et al., 2009; Baer et al., 2009; Kanitkar et al., 2010; Jayaraman et al., 2011; Rao, 2011; Kartha et al., 2012).

Section 6.3.6.6 elaborates a wide range of possible approaches and quantifies them in terms of levels of emissions reductions for various world regions. One recent example is Winkler et al. (2013), which evaluates several approaches for mitigation of and adaptation to climate change, and suggests that these call for more mitigation in wealthier countries. Recent research is also comparing various measures of equity for climate policy within developing countries (Casillas and Kammen, 2012). Section 13.13 assesses existing and proposed agreements in light of these criteria.

Table 13.2 | Description of recent proposals for climate change policy architectures.

Proposed Architecture (recent references)	Description
Strong multilateralism	
Indicator-linked national participation and commitments (Baer et al., 2009; Chakravarty et al., 2009; Frankel, 2010; Bosetti and Frankel, 2011; WBGU, 2009; Cao, 2010c; BASIC Project, 2007; Winkler et al., 2011)	All countries adopt emissions targets and timetables, with time of participation and/or target levels based on one or more indicators (per capita income, economic cost as percentage of national income, historical emissions). Targets can both be reductions in emissions growth rates as well as absolute reductions.
Per capita commitments (Agarwala, 2010)	Countries implement equal per capita emissions targets, resulting in significant emissions increases for many developing countries, and significant decreases for industrialized countries.
Top-down burden sharing (Baer et al., 2009; Kartha et al., 2012; Cao, 2010c; Kanitkar et al., 2010; Jayaraman et al., 2011)	Emissions targets based on equal per capita emissions, mitigation burden proportional to cumulative emissions and ability to pay, countries with similar economic circumstances have similar burdens, and poorest countries and individuals exempt from obligations.
Sectoral approaches (Sawa, 2010; Schmidt et al., 2008; Barrett, 2010; den Elzen et al., 2008)	Countries develop national emissions targets by sector, and governments make international commitments to implement policies to achieve targets (Sawa, 2010) or based on staged sectoral approach (den Elzen et al., 2008); can be developed in a portfolio of treaties (Barrett, 2010). Alternatively, developing countries pledge to meet voluntary sectoral targets; reductions beyond targets can be sold to industrialized countries (Schmidt et al., 2008).
Portfolio system of treaties (Barrett, 2010; Stewart et al., 2012)	Separate international treaties concluded for different sectors, different GHGs. Treaty obligations apply globally, and developing countries offered financial assistance to aid compliance and induce participation. Trade restrictions used to enforce agreements in trade-sensitive sectors.
Harmonized national policies	
Global emissions permit trading system (Ellerman, 2010)	The EU ETS serves as prototype for a global emissions trading system. Design informed by EU ETS experience, which has a central coordinating institution (the European Commission), mechanisms to expand participation to new Member States, and effective financial flows resulting from trading. Distributional impacts addressed by specific design features.
International carbon tax (Cooper, 2010; Nordhaus, 2008; Metcalf and Weisbach, 2009)	A common charge levied on all global GHG emissions, most practically upstream (at oil refineries, gas pipelines, mine mouths, etc.). Each country collects and keeps its own revenues. Charges rise over time according to schedule to induce cost-effective technological change. Distributional impacts addressed by allocation of revenues.
Hybrid market-based approaches (Fell et al., 2012)	A tradable emissions permit system includes a price ceiling, a price floor, or a combination of the two (a price collar). System functions like a hybrid of a tax and a tradable permit system. The price ceiling (often called a 'safety valve') can take the form of unlimited allowances sold at a fixed price or a limited allowance reserve.
Decentralized architectures and coordinated national policies	
Linked domestic cap-and-trade systems (Jaffe and Stavins, 2010; Jaffe et al., 2009; Bernstein et al., 2010; Metcalf and Weisbach, 2012; Ranson and Stavins, 2013)	Domestic and international emissions trading and emissions reduction credit systems linked, directly or indirectly, to achieve cost savings. Direct linkages require more coordination, while indirect linkages (of cap-and-trade systems through a common credit system, for example) require less. Linkage achieved independently (as a bottom-up architecture), as a transition to a new top-down architecture, or as an element of a broader climate agreement.
Linked heterogeneous policy instruments (Metcalf and Weisbach, 2012)	Domestic and international emissions trading systems linked with carbon tax systems, allowing emissions permits from one country to be remitted as tax payments, and/or allowing payments in excess of the tax in one country to satisfy the requirement to own a permit in another. Alternatively, fixed emissions standards (or even technology standards) linked with taxes or tradable permit systems across countries or regions.
Technology-oriented agreements (Newell, 2009, 2010a; de Coninck et al., 2008)	International climate change agreements to cover issues such as knowledge sharing and coordination, joint research and development, technology transfer, and/or technology deployment mandates or incentives. Distributional impacts affected by intellectual property sharing rules.

13.4.3 Recent proposals for future climate change policy architecture

An extensive literature has examined what options could be pursued 'post-2012', after the end of the first commitment period (CP1) of the Kyoto Protocol. The literature now contains several surveys of diverse proposals (see summaries of pre-2007 literature in Höhne et al., 2008; Moncel et al., 2011; Aldy and Stavins, 2010b; Rajamani, 2011b, 2012a; IPCC, 2007, Chapter 13). Table 13.2 describes recent proposals for climate policy architectures. Qualitative and quantitative performance assessments of these proposals, where available, are surveyed in Section 13.13.

13.4.4 The special case of international cooperation regarding carbon dioxide removal and solar radiation management

Since the publication of AR4, carbon dioxide removal (CDR) and solar radiation management (SRM) have received increasing attention as a means to address climate change, distinct from mitigation and adaptation. These two approaches are often collectively referred to as 'geoengineering' or 'climate engineering' (for more detail, see Working Group (WG) I contribution to the IPCC Fifth Assessment Report (AR5) Section 6.9). Carbon dioxide removal refers to techniques to extract GHGs directly from the atmosphere and store them in sinks, or to directly enhance such sinks. Solar radiation management aims to reduce the amount of solar radiation absorbed by the Earth's surface. Proposed SRM projects can be atmospheric (e.g., cloud brightening or adding reflective sulphate particles to the lower stratosphere), terrestrial (e.g., enhancing the albedo of the ground, or painting pavements and roof materials white to reflect solar radiation) and space-based (e.g., placing mirrors in space). See WGI report, Section 7.7, for details of these.

Some SRM options (e.g., injecting sulphate particles into the lower stratosphere) may be inexpensive enough for individual states (Barrett, 2008a) and even non-state actors, such as wealthy individuals, to undertake (Barrett, 2008a; Victor, 2008; Lin, 2009; Victor et al., 2009; Bodansky, 2011b). CDR and other SRM approaches might need to be implemented by numerous countries in order to be effective (Humphreys, 2011). Some SRM options may also have specific regional impacts (e.g., regional temperature and precipitation effects, leaf albedo enhancement, or ocean circulation modification), providing direct and perhaps excludable benefits to actors undertaking them (Millard-Ball, 2012) and external costs to others (Ricke et al., 2010, 2013). See also WGII 19.5.4 for detailed discussion of the risks of SRM.

Smaller-scale actors that are particularly vulnerable to climate change impacts may perceive advantages to be first-movers with SRM, in order to ensure both global climate protection and a favourable distribution of regional impacts from their selected SRM projects (Ricke et al., 2010; Millard-Ball, 2012). Hardly any cooperation might be needed for SRM's development and deployment—indeed, countries facing severe impacts might rush to launch a preferred SRM project (Millard-Ball, 2012). If the benefits of such an SRM project outweigh the adverse side-effects, and its costs are indeed low, then such an SRM project might be desirable. But such unilateral action could also produce significant adverse side-effects and costs for other actors, if the SRM option chosen is one that secures climate benefits for one part of the world while creating climate or other damages in other parts (Lin, 2009). Solar radiation management may also be ineffective in mitigating some climate impacts, for example the acidification of oceans from absorption of excessive CO_2 (Humphreys, 2011). Further, SRM does not reduce concentrations of atmospheric GHGs, and interrupting SRM after concentrations have risen significantly could allow temperatures to rise rapidly (see also Smith and Rasch, 2012).

Solar radiation management poses the converse of the collective action and governance challenges arising from emissions-reduction efforts: rather than mobilizing hesitant action to limit emissions, SRM governance involves restraining hasty unilateral action (Victor, 2008; Victor et al., 2009; Virgoe, 2009; House of Commons Science and Technology Committee, 2010; Lloyd and Oppenheimer, 2014; Millard-Ball, 2012; Bodansky, 2011b). One of the main issues for international cooperation will be to develop institutions and norms to address potential negative consequences of SRM in other social or environmental fields, or for parts of the world either not protected or negatively affected by the SRM option chosen. Thus, some analysts have recommended that international governance be organized for SRM research and testing, to learn about the benefits and side-effects of SRM options, to develop institutions to decide if and when to deploy SRM, to learn how to maintain SRM capabilities, and to monitor and evaluate this research and its use (Victor et al., 2009; Blackstock and Long, 2010; Lin, 2009; Solar Radiation Management Governance initiative, 2011).

Some existing international agreements may be relevant to geoengineering. The UNFCCC already includes a provision, Article 4.1(f), requiring assessment of the adverse impacts of mitigation measures. The UN Convention on Law of the Sea contains important provisions on environmental protection (Redgwell, 2006), and may have increased significance with regards to the governance of marine-based carbon dioxide storage or geo-engineering options (Virgoe, 2009). Under the London Convention and Protocol, the International Maritime Organization (IMO) held that, given the uncertainty surrounding negative impacts, ocean fertilization other than 'legitimate scientific research' ought not be permitted (Reynolds, 2011; IMO resolution LC-LP.1, 2008 and LC-LP.2, 2010). Several multilateral fora have recently taken up the issue of SRM. The 1992 Convention on Biological Diversity (CBD) adopted a decision calling for a moratorium on 'geo-engineering activities that may affect biodiversity' (Convention on Biological Diversity, 2010; Tollefson, 2010). Other existing multilateral treaties and agreements that may relate to geo-engineering include: the 1977 UN Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques (the ENMOD Convention) (though it restricts only 'hostile' actions); the convention on Environmental Impact Assessment in a Transboundary Context (UNECE, 1991); the 1959 Antarctic Treaty System (US Department of State, 2002); and ongoing developments in human rights law and in environmental law (Reynolds, 2011; Convention on Biological Diversity, 2012). Further, the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (United Nations, 2002) may apply to the use of sun-deflecting mirrors in space.

13.5 Multilateral and bilateral agreements and institutions across different scales

This section builds on the description of the climate policy landscape in Section 13.3.1 and plausible climate policy architectures in Section 13.4. It considers the experience and evolution of international and transnational cooperation on climate change between states and non-state actors since 2007 when the Fourth Assessment Report of the IPCC was published.

13.5.1 International cooperation among governments

13.5.1.1 Climate agreements under the UNFCCC

The UNFCCC's universal membership provides it with a high degree of legitimacy among parties around the world (Karlsson-Vinkhuyzen and McGee, 2013). Steps taken under the Convention and its Kyoto Protocol have led to more extensive action than under other forms of international cooperation on climate change.

Evolution of the multilateral climate regime since AR4
At COP-13 in Bali in 2007, discussions on long-term cooperative action under the Convention turned into negotiations under the Bali Action Plan (UNFCCC, 2007a). Also in Bali, countries agreed to MRV of mitigation commitments or actions by developed countries and mitigation actions by developing countries and support for those. Under the Copenhagen Accord (UNFCCC, 2009a) and Cancún Agreements (UNFCCC, 2010), Forty-two developed countries (including the 27 EU member states) submitted absolute reduction commitments against various base years in the form of quantified economy-wide emissions targets for 2020. Fifty-five developing countries and the African Union submitted information on NAMAs to the UNFCCC (as of May 2013), which are subject to domestic and international MRV. These 55 developing countries expressed their proposed goals in a variety of ways (e.g., relative emission reductions, deviation below business-as-usual, absolute reductions, and goals related to carbon neutrality); 16 proposed economy-wide goals for mitigation of GHGs. Since 2010, no major economy has significantly changed its emission reduction proposal under the UNFCCC, though some countries have clarified their assumptions and business-as-usual emission levels (UNEP, 2010, 2011, 2012, 2013b; den Elzen et al., 2013a; Sharma and Desgain, 2013; UNFCCC, 2013c). Figure 13.3 displays the different categories of actions and pledges taken by countries under the Cancún Agreements and the Kyoto Protocol as of September 2013.

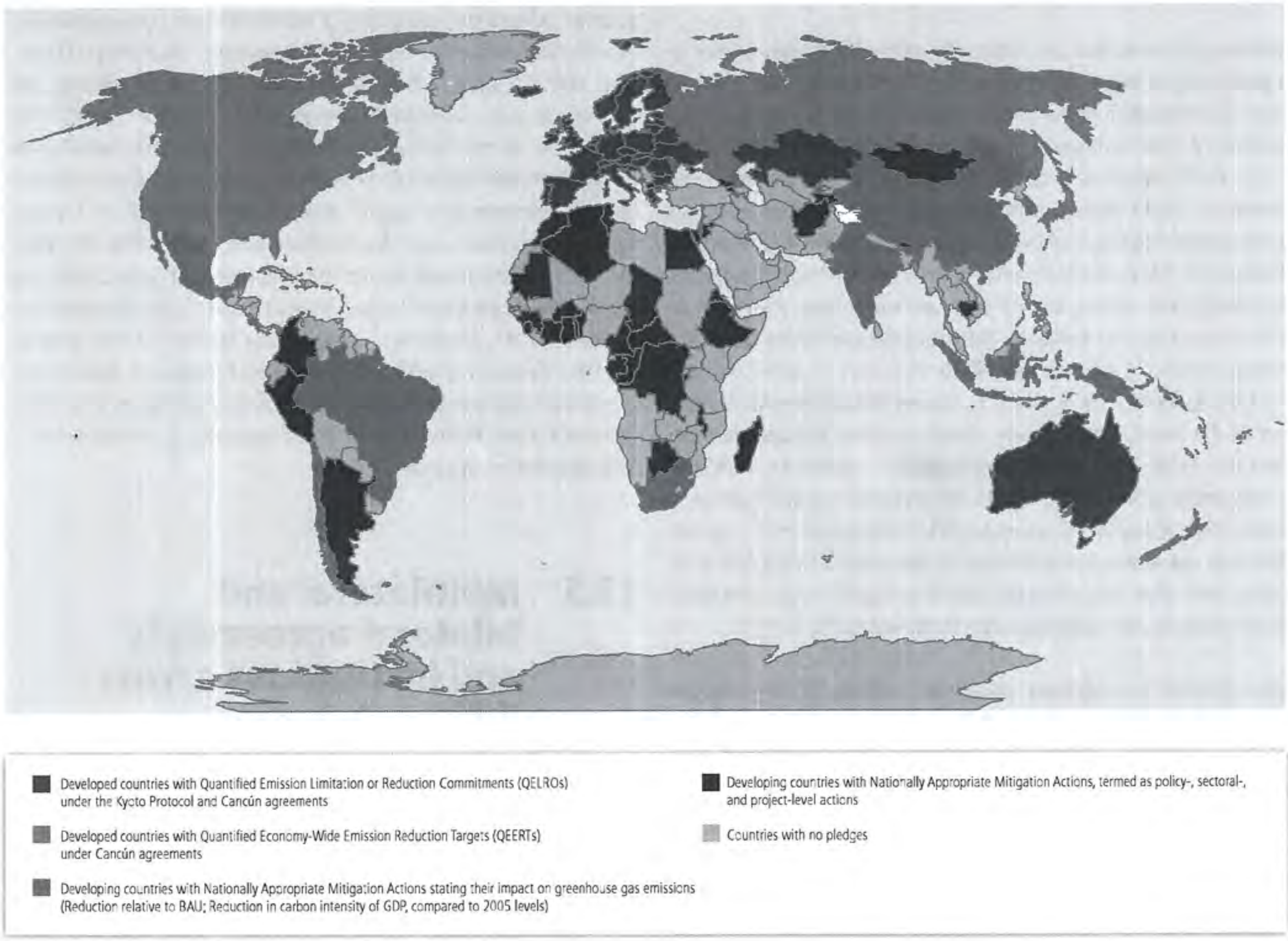


Figure 13.3 | Global map showing the different categories of reduction proposals or commitments for 2020 under the Cancún Agreements and Kyoto Protocol, based on UNEP (2012, 2013b) with underlying data supported by UNFCCC (2011b, 2012d, 2013c).

COP-17 in Durban in 2011 produced the Durban Platform for Enhanced Action (UNFCCC, 2011a), in which the delegates agreed "to launch a process to develop a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties" (UNFCCC, 2011a) and "complete its work as early as possible but no later than 2015 in order to adopt this protocol, another legal instrument or an agreed outcome with legal force at the twenty-first session of the Conference of the Parties and for it to come into effect and be implemented from 2020" (UNFCCC, 2011a).

Evolution of coalitions among UNFCCC parties

New and existing coalitions of countries have engaged in the UNFCCC negotiations, each presenting coordinated positions. Several distinct coalitions of developing countries have formed to negotiate their divergent priorities. Examples include the G77 & China, which represents 131 developing countries operating in the UNFCCC and the UN system more broadly and which contains sub-groups such as the African Group, the Least Developed Countries, and the Arab Group; the Alliance of Independent Latin American and Caribbean states; and a 'like-minded developing country' group that included China, India, and Saudi Arabia (Grubb, 2013). Other coalitions organized to influence UNFCCC negotiations include the Alliance of Small Island States (AOSIS), which has played a significant role in UNFCCC negotiations since the early 1990s; various groupings of industrialized countries, including the Umbrella Group; the Environmental Integrity Group, which was the first coalition to include both industrialized and developing countries; the BASIC countries (Brazil, South Africa, India and China) (Olsson et al., 2010; Rong, 2010; Nhamo, 2010); the Coalition of Rainforest Nations, which has increased the salience of forests in climate negotiations; and other active coalitions not limited to the climate context, for example the Comision Centroamericana de Ambiente y Desarollo and the Bolivarian Alliance for the Americas.

Negotiations under the Kyoto Protocol

Negotiations on a second commitment period (CP2) of the Kyoto Protocol were launched in Montréal in 2005. These negotiations concluded in late 2012 at COP-18 in Doha, Qatar with a decision and amendment establishing the second commitment period of the Protocol for 2013–2020. However, a number of Annex I countries (Belarus, Canada, Japan, New Zealand, Russia, the United States, and Ukraine) decided not to participate in the second commitment period. The other Annex I countries (Australia, the EU and its member states, Iceland, Liechtenstein, Monaco, New Zealand, Norway, Switzerland, and Ukraine) adopted quantified emission reduction commitments (Figure 13.3), covering 13 % of global GHG emissions at 2010 emission levels (UNFCCC, 2012d; JRC/PBL, 2013). At COP-18 in Doha in 2012, parties also agreed upon rules for transferring surplus Kyoto emissions allowances from the first to the second period. These rules are assessed in Section 13.13.1.1, and the evolution of market-based flexibility mechanisms in the UNFCCC negotiations is discussed in Section 13.4.2.3.

New institutions under the UNFCCC and the Kyoto Protocol

The UNFCCC and its Kyoto Protocol have brought about a number of new institutions focused on adaptation (funding and coordination), finance, and technology. The Adaptation Fund was established to provide direct access to financing for developing countries and is governed by a majority of developing countries. The Adaptation Committee was established to coordinate previously fragmented aspects of adaptation policy under the Convention, with modalities and linkages to other institutions to be defined (UNFCCC, 2011c) (see Section 13.11.1.1). The GCF is accountable to the Conference of the Parties, and, when it is fully operational, may be a major channel for the provision of climate finance (Brown et al., 2011). The Standing Committee on Finance supports the parties in coordinating and providing accountability for the financial mechanism of the Convention. The Climate Technology Centre and Network (CTCN), together with the Technology Executive Committee (TEC), was established to exchange information regarding technology development and transfer for adaptation and mitigation (UNFCCC, 2011c).

13.5.1.2 Other UN climate-related forums

Acting on climate change may require functions other than negotiation under the UNFCCC or other forms of high-level cooperation, such as analytical support and implementation assistance for mitigation and adaptation efforts. A diverse set of forums both within and outside the UN system has taken up the issue of climate change since AR4, possibly contributing to broader institutional learning and effectiveness (Depledge, 2006; Stewart et al., 2012).

The United Nations Environment Programme (UNEP) has had a natural concern with climate change for many years, given its mission, and it collaborates closely with the UNFCCC. Since AR4, UNEP has provided increasingly significant analytical support to the international process, in part through its emissions-gap reports (UNEP, 2010, 2012, 2013b; Höhne et al., 2012b; Hof et al., 2013), but also through a wide range of other analytical efforts and support for institution building.

United Nations forums beyond the UNFCCC are increasingly addressing funding for adaptation and mitigation. Fragmentation in the various objectives, conditions, and eligibility requirements of the different funds may make it difficult for developing countries to identify and access appropriate funding (Czarnecki and Guilanpour, 2009). The literature examines the relationship between adaptation and development finance, including concerns about measuring official development assistance (ODA) and how much adaptation funding is 'new and additional' (Stadelmann et al., 2010; Smith et al., 2011). A number of developing countries have established "national funding entities to coordinate domestic and international funding for adaptation with development funding" (Smith et al., 2011).

Other UN agencies have also addressed the connections of climate change with human development (UNDP, 2007; UNDESA, 2009), the

CO_2 emissions gap (Convention on Biological Diversity, 2012; Höhne et al., 2012b), finance (AGF, 2010), and human rights (see Section 13.5.2.2).

The Montreal Protocol on Substances that Deplete the Stratospheric Ozone Layer (concluded in 1987 under UN auspices)—and the Protocol's subsequent amendments, adjustments, and decisions—have also contributed to reductions in GHGs. One notable proposed amendment would accelerate the phaseout of substitutes of ozone depleting substances that are also strong GHGs (Mauritius & Micronesia, 2009; Velders et al., 2012).

13.5.1.3 Non-UN forums

Climate change is increasingly addressed in forums for international cooperation outside of the UN. The AR4 (IPCC, 2007, Chapter 13) assessed several partnerships focused on particular themes, technologies, or regions.

Some international partnerships have defined themselves as complements to the UNFCCC rather than as alternatives. For example, the REDD+ Partnership helps coordinate measures for reducing emissions from deforestation and degradation (REDD) in the UNFCCC process. The Partnership focuses on conservation, sustainable forest management, and forest carbon stock enhancement. In 2010, more than 50 countries signed a non-binding agreement to pledge more than 4 billion USD to REDD+ (Bodansky and Diringer, 2010). Michaelowa (2012a) and Stewart el al. (2009) describe multiple avenues for climate change financing to assist transitions to low-carbon technologies, such as through the International Renewable Energy Agency (IRENA). Established in 2009, IRENA seeks to advance the development and transfer of renewable energy technologies, with a focus on financing renewable energy in its 163 member and signatory states (plus the European Union) (Florini, 2011; International Renewable Energy Agency, 2013).

The MEF, organized by the United States, provides a forum for informal consultation. Its members—Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Mexico, Russia, South Africa, the United Kingdom, and the United States—together account for about 70 % of global GHG emissions (JRC/PBL, 2013). Its meetings are intended to advance discussion of international climate change agreements (MEF, 2009), and it has generated a related Clean Energy Ministerial. MEF participants recognize the group as a venue for discussion rather than a forum for negotiating binding agreements. The MEF produces a chairs' summary instead of formally agreed text (Leal-Arcas, 2011). The existence of the MEF may be evidence of an overall increase in the fragmentation of global environmental governance (Biermann and Pattberg, 2008; Biermann, 2010). Some may also be concerned about a small set of large countries reaching even informal decisions that affect a much larger set, and some may not be comfortable with a process chaired by a single nation (Stavins, 2010).

The Group of Twenty (G20) finance ministers from industrialized and developing economies could have the capacity to address climate finance, building on its core mission to discuss economic and finance policy. The make-up of the G20 is similar to that of the MEF, with the addition of Argentina, Saudi Arabia, and Turkey. Houser (2010) finds that the G20 might help to accelerate the deployment of clean energy technology, help vulnerable countries adapt to climate change impacts, and help phase out inefficient fossil-fuel subsidies. At its meeting in Pittsburgh in 2009 (G20, 2009), the G20 gave considerable attention to climate change policy issues, in particular to fossil-fuel subsidies. Likewise, since 2005, the smaller Group of Eight (G8) heads of state and government have held a series of meetings relating to climate change and recognized the broad scientific view that the increase in global average temperature above pre-industrial levels ought not exceed 2 °C (G8, 2009). Van de Graaf and Wsetphal (2011) explore both opportunities for and constraints on the G20 and G8 with regard to climate.

Two forums of growing importance, providing analytical support for international cooperation on climate change, are the International Energy Agency (IEA) and the OECD. While the IEA has limited its membership to industrialized oil-importing countries (Scott, 1994; Goldthau and Witte, 2011), the OECD has granted membership to advanced developing countries. Both institutions have received increasingly strong mandates by their members to provide analytical support for climate change mitigation decisions. The OECD has a unit for economic analysis of climate policy and impacts, and already plays a role in building knowledge (OECD, 2009). The IEA could play a key role to reduce uncertainty about countries' performance by collecting, analyzing, and comparing energy and industry-related emissions data (Harvard Project on Climate Agreements, 2010). The IEA and OECD have formed and jointly manage the Climate Change Expert Group, whose explicit mission is to provide analytical support on technical issues to the international negotiations.

The Cartagena Dialogue for Progressive Action includes around 30 industrialized and developing countries, which have met both during and between formal sessions since 2009. The Dialogue is open to countries working toward an ambitious, comprehensive, and legally binding regime in the UNFCCC, and who are committed to domestic policy to reduce emissions. The aim of the Dialogue is to openly discuss positions, to increase understanding, and to explore areas where convergence and enhanced joint action could emerge (Oberthür, 2011).

In February 2012, a group of seven partners (Bangladesh, Canada, Ghana, Mexico, Sweden, and the United States, together with the UNEP) launched a new 'Climate and Clean Air Coalition' as a forum for dialogue among state and non-state actors outside the UNFCCC process. The goal of the Coalition is to reduce levels of black carbon, methane, and hydrofluorocarbons (HFCs) among its 34 state members (including the European Commission) in collaboration with nine international organizations and 29 non-state partners (as of September 2013). The Coalition has received funding from a number of countries, including Canada, Japan, and the United States to implement projects (Blok et al., 2012; UNEP, 2013a).

New initiatives on international cooperation for adaptation and its funding have also been created, such as the World Bank's Pilot Program on Climate Resilience, and the European Commission-established Global Climate Change Alliance (GCCA), which pledges regional and country-specific finance.

13.5.2 Non-state international cooperation

13.5.2.1 Transnational cooperation among sub-national public actors

A prominent development since AR4 is the emergence of a large number of international agreements between non-state entities (den Elzen et al., 2011a; Höhne et al., 2012b; Hare et al., 2012). These are most commonly referred to as 'transnational climate governance initiatives' (Biermann and Pattberg, 2008; Pattberg and Stripple, 2008; Andonova et al., 2009; Bulkeley et al., 2012). In the most comprehensive survey, (Bulkeley et al., 2012) document 60 of these initiatives, which can be grouped into four principal types: public-private partnerships, private sector governance initiatives, non-governmental organization (NGO) transnational initiatives, and sub-national transnational initiatives. The first two, involving private actors, are discussed in Section 13.12.

NGO transnational initiatives attempt to influence the activities of corporations directly through transnational partnerships, some of which involve collaboration with the private sector. They have set up certification schemes for carbon offset credits, such as the Gold Standard, which is limited to renewable energy and demand-side energy efficiency projects, and the Community Carbon and Biodiversity Association standard, which aims to increase the quality of forestry credits (Bayon et al., 2007; Bumpus and Liverman, 2008). Certified offset credits have commanded a price premium above other ('standard') credits (Sterk and Wittneben, 2006; Ellis et al., 2007; Nussbaumer, 2009; Newell and Paterson, 2010). These certification schemes have been used for the Voluntary Carbon Market as well as for the CDM (Conte and Kotchen, 2010).

Sub-national transnational initiatives involve sub-national actors, such as city-level governments, collaborating at an international scale. One example of this form of cooperation is the International Council for Local Environmental Initiatives (ICLEI)—Local Governments for Sustainability network. This organization has taken action through its Cities for Climate Protection programme from 1993 and more recently through a partnership the C40 Cities Climate Leadership Group (Kern and Bulkeley, 2009; Román, 2010; Bulkeley et al., 2012). A World Mayors Summit in November 2010 had participation from 138 cities and agreed on a Global Cities Covenant on Climate, otherwise known as the Mexico City Pact. A related initiative, the 'carbonn' Cities Climate Registry, is an effort of local governments to regularly measure, report, and verify cities' actions on climate change mitigation and adaptation (Chavez and Ramaswami, 2011; Ibrahim et al., 2012; Otto-Zimmermann and Balbo, 2012; Richardson, 2012). Recognition of local governments as governmental stakeholders in paragraph I.7 of the Cancún Agreements is a reflection of the growing role of sub-national transnational cooperation in the UNFCCC processes.

Larger sub-national units have developed transnational collaborative schemes. Most notable are the North American sub-federal cap-and-trade schemes, including the Western Climate Initiative (WCI). The WCI was originally envisaged to link state and provincial cap-and-trade systems in seven western U.S. states and four Canadian provinces beginning in 2012. The original aim of the initiative was reducing GHG emissions by the member states and provinces to 15 % below 2005 levels by 2020 (Rabe, 2007; WCI, 2007; Selin and VanDeveer, 2009; Bernstein et al., 2010). While the U.S. state of California's ETS began operating in January 2013, the launch of the WCI system has been delayed. The WCI currently includes only California and Québec, although Ontario, British Columbia, and Manitoba are considering accession.

13.5.2.2 Cooperation around human rights and rights of nature

Human rights law could conceivably frame an approach to climate change (Bodansky, 2010b; Bell, 2013; Gupta, 2014). Some recent literature argues that a human rights framing helps 'to counteract gross imbalances of power' between states and individuals (Sinden, 2007; Bratspies, 2011; Akin, 2012). The human rights approach to climate change has been acknowledged by the UN Human Rights Council in its Resolution 7/23 and the Office of the United Nations High Commissioner for Human Rights (UNHRC, 2008; Limon, 2009; OHCHR, 2009). The literature discusses a variety of specific issues, including the implications for climate adaptation; the impacts of climate change on human rights to water, food, health, and development; obligations to undertake mitigation actions; and whether human rights law implies an obligation to receive climate refugees.

Refugees displaced from their homes due to climate change may strain the capacity of existing institutions (Biermann and Boas, 2008). However, policies to address climate refugees face legal hurdles, including the issue of causality: who is to be held responsible, who is the rights-bearer, and the issue of standing (Limon, 2009). Proposals have been made in the literature for a new protocol to the UNFCCC, a new convention, and funding mechanisms to address the issues associated with climate refugees (Biermann and Boas, 2008; Docherty and Giannini, 2009). Such efforts could build on the 1951 Geneva Convention Relating to the Status of Refugees. In the absence of coordinated efforts, the Special Procedures and the Universal Periodic Review of the Human Rights Council are advancing the human rights and climate change agenda (Cameron and Limon, 2012).

In 2010, the government of Bolivia convened government and non-government representatives in the World People's Conference on Climate Change and the Rights of Mother Earth, which culminated in a People's Agreement (WPCCC and RME, 2010). The participation of social movements in international cooperation on climate change may enhance recognition of 'radical climate justice' (Roberts, 2011) and an approach to law that seeks to establish 'rights of nature' (Cullinan, 2002; Sandberg and Sandberg, 2010; Aguirre and Cooper, 2010).

13.5.3 Advantages and disadvantages of different forums

The literature has considered the strengths and weaknesses of negotiating climate policy across multiple forums and institutions. Some studies suggest that, in addition to its own action, the UNFCCC effect of catalyzing efforts by others and providing coherence to multiple initiatives may result in greater aggregate impact (Moncel and van Asselt, 2012). Other literature suggests that 'regime complexes' may emerge from smaller 'clubs' and then expand (Keohane and Victor, 2011; Victor, 2011). Regimes need (external) incentives for participation and (internal) incentives for compliance (Aldy and Stavins, 2010c). A key advantage of smaller forums or 'clubs' may be greater efficiency in the negotiation process, as emphasized in the general political science literature on negotiations (for example, Oye, 1985). But the literature also reflects key disadvantages, including that such clubs lack universality and hence legitimacy (Moncel et al., 2011), and that the environmental effectiveness of clubs may be undercut by leakage of emissions sources to other countries outside the club (Babiker, 2005). Some have suggested clubs as a way forward outside the UNFCCC, while others suggest they could contribute to the UNFCCC, for example by assisting in catalyzing greater ambition (Weischer et al., 2012). Several smaller 'clubs' that cut across categories (e.g., public/ private) and scales (from international to local) are assessed in Section 13.5.1.2. Flexibility is another advantage cited for smaller clubs. Climate change mitigation through 'clubs' is not necessarily superior (Keohane and Victor, 2011) and action through this form of cooperation has to date not brought about high levels of participation and action. Smaller clubs must address conflicts where the climate change regime intersects with other major policy regimes (Michonski and Levi, 2010). Analysis of existing clubs suggests they enable incremental change and suggests that a set of incentives (related to trade, investment, labour mobility, or access to finance) could turn these into 'transformational clubs' (Weischer et al., 2012).

In a fragmented world, linking multiple agreements into a coherent whole is a major challenge. The aggregate effectiveness (in terms of the criteria discussed in Section 13.2) of the landscape of climate agreements and related institutions (Figure 13.1) can be enhanced by coordinated linkages among multiple elements. The actual forms and effects of policy linkages, existing or future, must be evaluated in each context. Policy linkages across the landscape of agreements on climate change might take several forms, such as mandated action and reporting by subsidiary bodies, agreed links between institutions (e.g., memoranda of understanding), loose coordination, information sharing, and delegation. The literature on transnational governance acknowledges a gap in that "interactions are understudied in all areas of transnational governance" (Weischer et al., 2012). Some characteristics of potential linkages may stimulate their formation, for example, competition among public and private governance regimes (Helfer and Austin, 2011), accountability (Bäckstrand, 2008; Ballesteros et al., 2010), learning (Kolstad and Ulph, 2008), and experimentation. Related literatures suggest that other important characteristics of linkages across regime components may be reciprocity (Saran, 2010), relationships of conflict or interpretation (ILC, 2006), collaboration (Young, 2011), the catalytic role of the UNFCCC (UNFCCC, 2007a), NGOs as norm entrepreneurs (Finnemore and Sikkink, 1998), evaluation of policy approaches (Stewart and Wiener, 2003; Greenstone, 2009), and delegation to other institutions (Green, 2008).

13.6 Linkages between international and regional cooperation

13.6.1 Linkages with the European Union Emissions Trading Scheme

Due to the scale effects that occur when carbon markets are enlarged, market-based mechanisms may be an important means of regional policy integration. The largest carbon market is the EU ETS, which began operating in 2005, and now includes all 28 European Union member states and is linked with the Norwegian system. The EU ETS is described and evaluated in detail in Section 14.4.2.1.

The EU ETS interacts with international carbon markets through the project-based Kyoto mechanisms. Import of units through international emissions trading is not allowed, but companies covered by the EU ETS can import CDMs and JI credits. A relatively liberal import regime for the pilot phase was established in a 'Linking Directive' approved in 2004 (Flåm, 2009). Forestry credits were banned and additional criteria for large hydropower projects were set. For the EU ETS's second phrase, which corresponded to the Kyoto Protocol's first commitment period, 2008–2012, countries proposed import thresholds;

several proposals were adjusted downwards by the Commission. For the third phase, 2013–2020, imports were limited to credits from CDM projects registered before 2013 in the absence of an international climate change agreement. New (2013 inception or later) CDM projects can only be used in the EU ETS if located in least developed countries (LDCs) (Skjærseth, 2010; Skjærseth and Wettestad, 2010). However, CDM credits from new projects in non-LDCs can be accepted after 2013 if the EU has concluded a bilateral agreement with the country in question regulating their level of use.

The European Union could potentially link the EU ETS to other schemes, and legislation for the period until 2020 allows negotiation of such bilateral treaties. The EU and Australia have already agreed to a one-way indirect link to commence on 1 July 2015, meaning that EU credits will be allowed for compliance under the Australia system (European Commission, 2012). This agreement will transition to a two-way direct link by no later than 1 July 2018, provided that the Australian system goes forward.

13.6.2 Linkages with other regional policies

The Asia-Pacific Partnership for Clean Development and Climate, which was time-limited and has now concluded, involved about 50 % of the world population, GHG emissions, and world economic output (Kelly, 2007). The partnership included countries that had not ratified the Kyoto Protocol, and while it was 'soft' in terms of legal bindingness, it may have had a modest impact on governance (Karlsson-Vinkhuyzen and van Asselt, 2009; McGee and Taplin, 2009) and encouraged voluntary action (Heggelund and Buan, 2009). After the end of the Partnership, the Global Superior Energy Performance Partnership (GSEP) Clean Energy Ministerial took over some of the Partnership's activities.

In addition to coordination by international organizations, such as ICLEI—Local Governments for Sustainability, voluntary mitigation action of cities is taking a regional/global character (Kern and Bulkeley, 2009). In Europe, the Climate Alliance has about 1700 member cities from a number of countries. The Climate Alliance has supported rainforest conservation projects in the Amazon region (Climate Alliance, 2013).

13.7 Linkages between international and national policies

As the landscape of multilateral and other international agreements on climate has become more complex, the interactions between international and national levels have become more varied.

13.7.1 Influence of international climate policies on domestic action

International policy may trigger more ambitious national policies. Treaties provide greater certainty that others will act, thus addressing key concerns that countries will free ride. International climate policy can shape domestic climate discourse, even if it may not be the main inspiration for proactive action (Tompkins and Amundsen, 2008).

National policies also affect the effectiveness of international policies. The implementation of international policy is affected by national political structure. Examples of studies on how varying domestic political structures affect the implementation of international policies include studies in: Italy (Massetti et al., 2007), France (Mathy, 2007), Canada (Harrison, 2008), China (Teng and Gu, 2007), the UK (Barry and Paterson, 2004; Compston and Bailey, 2008) and the Netherlands (Gupta et al., 2007). National and sub-national settings, where actions may be less risky or more politically feasible, may also provide useful 'laboratories' to test policy instruments before implementation at the international level (Michaelowa et al., 2005; Moncel et al., 2011; Zelli, 2011).

13.7.2 Linkages between the Kyoto mechanisms and national policies

Linking national policies with international policies may provide flexibility by allowing a group of parties to meet obligations in the aggregate. The Kyoto Protocol (Article 4) provides for such inter-regional flexibility, and the European Union has taken advantage of the Protocol's provision through its internal burden sharing decision. This decision allowed the EU's Kyoto commitment of an 8 % emissions reduction below 1990 for the 2008–2012 period to be redistributed among EU-15 member states; commitments of these states range from −28 % (Luxembourg) to +27 % (Portugal) (Michaelowa and Betz, 2001; Hunter et al., 2011).

Use of the CDM and JI Kyoto mechanisms has been driven by national mitigation policies to achieve developed countries' emissions commitments. While governments of some developed countries buy emissions credits directly, others introduce instruments with emissions commitments for private companies, like the EU ETS; some countries, such as Denmark, have done both. These companies can then use emissions credits generated under the Kyoto Protocol to satisfy part of their commitments (Michaelowa and Buen, 2012). Another example is Japan's Industry Voluntary Action Plan that includes diverse sectors, each of which has its own target set either in absolute terms, in emissions' intensity, or in terms of energy consumption (Mitsutsune, 2012).

Many industrialized countries limit imports of credits generated by the Kyoto mechanisms for various reasons; two have been posited in the literature: (1) to keep the domestic carbon price high to induce technological diffusion and possibly innovation; and (2) to avoid diminishing environmental effectiveness by allowing required emissions-reduction to occur in other jurisdictions because of concerns about the quality of credits ('additionality'). For example, the European Union has prohibited the import of Assigned Amount Units (AAU) into the EU-ETS to prevent the use of surplus units from countries in transition, colloquially called 'hot air' (Michaelowa and Buen, 2012). Japanese companies have used AAUs from Green Investment Schemes for meeting their targets (Tuerk et al., 2010). In 2011, credits from certain CDM project types were banned for use in the EU-ETS from 2013 onwards (Schneider, 2011). The ban includes CERs generated from projects involving destruction of trifluoromethane (HFC-23) and nitrous oxide (N_2O) from adipic acid production.

The Kyoto mechanisms also interact with the national policies of countries in which projects are implemented. However, the CDM Executive Board decided that the effects of new policies implemented in host countries that reduce emissions should not be considered when assessing the additionality of new projects to avoid perverse incentives not to adopt mitigation policies (Winkler, 2004; Michaelowa, 2010). Instead, countries may subsidize renewable energy while generating CDM credits. There are indications that the availability of CDM credits has accelerated the introduction of feed-in tariffs in China (Schroeder, 2009). Freeing emission units for sale under international emissions trading requires national mitigation policies unless there is a surplus of units in a business-as-usual situation, as in countries in transition (Böhringer et al., 2007).

Investment law, defined through private international law and more than 3000 multilateral and bilateral investment treaties (UNCTAD, 2013), applies to the CDM and emissions trading contracts. Proposed standardized contracts link the CDM to investment law by covering the choice of language and the process and forum for dispute resolution. These contracts could expose contractors to the costs associated with international arbitration (Gupta, 2008; Klijn et al., 2009).

13.7.3 International linkage among regional, national, and sub-national policies

International linkages can be established among regional, national, or sub-national policies. These can be direct or indirect. Under direct linkage, the same units are valid throughout the linked systems. Under indirect linkage, a unit in a certified emission reduction credit system is accepted by multiple systems. Figure 13.4 shows sub-national, national, and regional GHG cap-and-trade schemes and existing and planned linkages between them. The only formal direct linkage between two trading schemes is that arranged between the Australian ETS and the EU ETS, which was officially announced in August 2012. A strong indirect linkage between carbon markets exists through the CDM, whose credits are accepted under the EU-ETS, the Australian Carbon Pricing Mechanism, and the New Zealand ETS. Nazifi (2010) finds that EU demand has driven the price for CDM credits.

Review of unilateral and bilateral direct linkages demonstrates that bilateral direct linkage reduces mitigation costs, increases credibility of the price signal, and expands market size and liquidity (Anger, 2008; Flachsland et al., 2009; Jaffe et al., 2009; Dellink et al., 2010; Cason and Gangadharan, 2011; Lanzi et al., 2012). However, direct linkage also raises a variety of concerns (Jaffe et al., 2009), including that linking can lead to a dilution of mitigation achieved through trading schemes, as linked systems are only as environmentally effective as the weakest among them (e.g., the one that allows imports of offsets with the lowest standards). Grubb (2009) also warns that countries may be unwilling to accept an increase of carbon prices that would result from linking with a more ambitious system.Tuerk et al. (2009) see the biggest challenges to linking in differential stringencies of targets in each system, varying degrees of enforcement, differences in eligible project-based credits, and the existence of cost-containment measures, such as price ceilings. Haites and Mehling (2009) highlight that only bilateral links (or reciprocal unilateral links) yield the full benefits of linkage. Bilateral links often face lengthy adoption procedures as well as legal and procedural constraints, whereas reciprocal unilateral links, possibly framed by an informal agreement, are often easier to implement and provide more flexibility for almost the same benefits.

Also attractive are indirect linkages among regional, national, or sub-national cap-and-trade systems, an approach that maintains the benefits of linkage without much of the downside. Such indirect linkages achieve cost savings and avoid risk diversification without the need for deliberative harmonization of emerging and existing cap-and-trade systems. Indirect linkage is attractive because de facto linkages limit potential distributional concerns and preserve a high degree of national control over allowance markets (Jaffe et al., 2009).

In addition, both direct and indirect linkages can occur among heterogeneous regional, national, and sub-national policy instruments (Metcalf and Weisbach, 2012). Some such linking would be relatively straightforward, such as forming a link between a cap-and-trade system and a carbon tax. Other links would be more challenging, such as between a cap-and-trade system and a quantity standard. Others would be even more difficult, such as between a cap-and-trade system and a technology mandate, and some linkages between heterogeneous policy instruments would simply not be possible (Metcalf and Weisbach, 2012).

13.8 Interactions between climate change mitigation policy and trade

Research on interactions between climate change mitigation policy and trade indicates a diversity of compatibilities, synergies, conflicts, and cooperative arrangements (Brewer, 2003, 2004, 2010; Cosbey, 2007; ICTSD, 2008; Cottier et al., 2009; Epps and Green, 2010; Rao, 2012; Leal-Arcas, 2013). Consideration of these and other issues and options needs to take into account the context of the provisions of the principal existing multilateral climate change framework (Yamin and Depledge, 2004) and multilateral trade framework (Hoekman and Kostecki, 2009). Negotiators acknowledged the opportunities for international cooperation on interactions between climate change and trade in both the UNFCCC (1992) and in a Ministerial Decision at the time of the negotiations of the Marrakech Agreement establishing the WTO (1994). But there is also a potential for conflict between climate and trade issues. According to Article 3.5 of the UNFCCC, "Measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade". The Kyoto Protocol notes in Article 2.3 that Annex I Parties "shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including … effects on international trade."

Trade and climate policy interact at many levels (Copeland and Taylor, 2005; Tamiotti et al., 2009; UNEP, 2009; UNCTAD, 2010; World Bank, 2010). For instance, on the one hand, according to Peters and Hertwich (2008), "almost one-quarter of carbon dioxide released to the atmosphere is emitted in the production of internationally traded goods and services" (see also Peters et al., 2011). Transportation associated with trade is another related issue (Conca, 2000). On the other hand, various climate change policies currently in place affect the relative prices of goods and services, which thereby affect trade flows and the total volume of traded goods (Whalley, 2011). Moreover, trade barriers and obligations regarding intellectual property (IP) rights of 'green technology' as well as many other WTO obligations impinge on climate policy (Thomas, 2004; Khor, 2010a; Johnson and Brewster, 2013). Victor (1995) suggested that lessons from the trade regime could be used in the development of the climate regime, but comparative governance studies of the trade and climate regimes have not been thoroughly utilized to gain insights into how the two regimes might address trade-climate interactions (Bell et al., 2012 an exception).

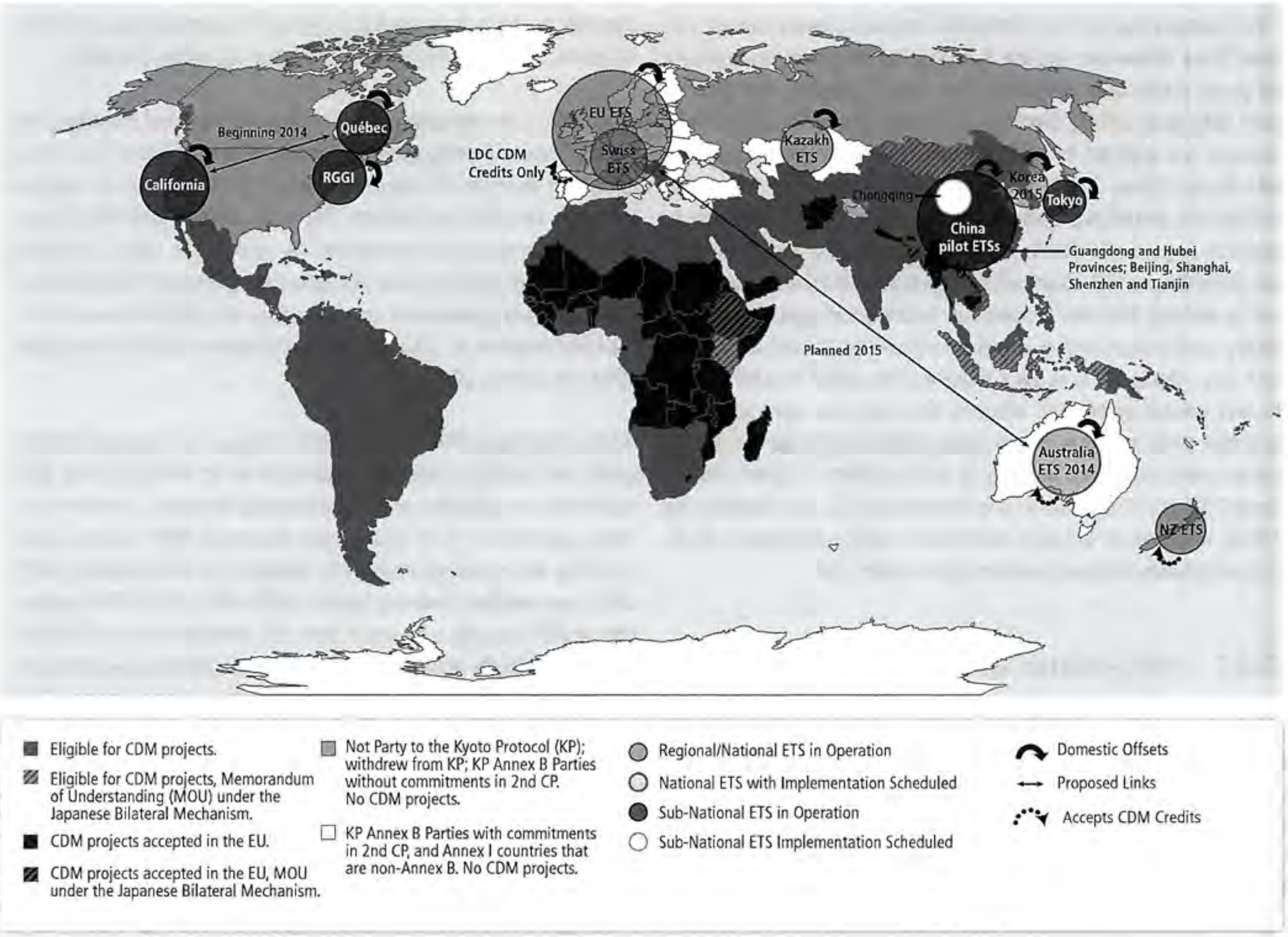


Figure 13.4 | Cap-and-trade schemes with existing and planned linkages. Linkage through proposed acceptance of offsets and Joint Implementation projects not displayed. In some cases, countries otherwise eligible to host CDM projects must first establish a Designated National Authority. Accurate as of March 2014.

The production of internationally traded goods gives rise to a 'labelling' issue, a problem for accounting purposes and also for possible policy intervention. The issue arises because a proportion of a country's GHG emissions resulting from the production of goods and services in one country may be 'embedded' in traded products that are consumed in other countries. At issue is whether to attribute the emissions to the producing (exporting) country or consuming (importing) country (Kainuma et al., 2000; Peters and Hertwich, 2008) (see also Sections 5.4.1 and 14.3.4.2). There is an ethical and equity issue about how to define climate responsibility and allocate climate mitigation costs (discussed in detail in Sections 3.3, 4.1, and 4.2). There is also a political and economic issue whether climate policy instruments ought to address production- or consumption-induced GHGs (Droege, 2011a, b; see also Section 14.3.4). Finally, there is a technical issue as territorial measurement is the current GHG accounting practice under the UNFCCC, and switching to consumption-induced measurement may be technically more difficult (Droege, 2011a; b; Peters et al., 2011; Caldeira and Davis, 2011).

There are significant differences among researchers and policymakers in their perspectives on the relationship between climate change and trade. These differences include fundamental empirical assumptions and policy preferences concerning the roles of markets and governments (Bhagwati, 2009), specifically concerning whether government measures are required to address market failures that produce climate change (Stern, 2007), or government regulations tend to create inefficiencies and distort trade (Krugman, 1979; Rodrik, 2011). Trade measures (e.g., trade sanctions, trade enticements, and trade-relevant domestic product standards; see Section 13.8.1 below) could be used to address free-rider problems of international agreements, specifically participation and/or compliance problems (Victor, 2010), and some (e.g., Victor, 2011) suggest these may be useful in achieving an effective climate agreement. However, there are also some who conclude that trade measures are an inappropriate tool to pursue climate change policy objectives, pointing to the possibility of 'green protectionism' (Khor, 2010a; Johnson and Brewster, 2013). The potential use of trade measures to enhance participation and/or compliance poses major institutional design questions (see Section 13.4).

13.8.1 WTO-related issues

A central issue for WTO members is whether policies are consistent with principles of non-discrimination. Most Favoured Nation Treatment prohibits favourable treatment of the goods, services, or corporations of any one member as compared with other members, while National Treatment prohibits less favourable treatment of foreign relative to domestic goods, services or corporations. Of the more than 60 WTO agreements that apply these principles, many are pertinent to climate change, including the General Agreement on Tariffs and Trade (GATT), the General Agreement on Trade in Services (GATS), the Agreement on Trade Related Intellectual Property Rights (TRIPs), the Agreement on Technical Barriers to Trade (TBT), the Agreement on Trade Related Investment Measures (TRIMs) and the Dispute Settlement Understanding (DSU), as well as agreements on subsidies, government procurement, and agriculture (Brewer, 2003, 2004, 2010; Cottier et al., 2009; Hufbauer et al., 2009; Epps and Green, 2010). Studies have suggested that ETSs can be designed to be compatible with WTO obligations (Werksman, 1999; Petsonk, 1999).

Trade issues concerning CDM projects have received special attention (Werksman et al., 2001; Rechsteiner et al., 2009; Werksman, 2009). Although no trade or investment disputes have arisen yet in connection with CDM projects, there is the possibility that they will in the future as the number and economic significance of CDM projects continues to increase. Significant attention has also been given to product labelling and standards issues that can arise in relation to the WTO Agreement on TBT (Appleton, 2009), which could be pertinent to the use of labels concerning 'food miles' (ICTSD, 2007; World Bank, 2010). Although long-distance air transport of agricultural products itself is GHG-intensive, the agricultural practices of many exporting countries are less GHG-intensive than those of the importing countries, and determining the relative GHG emissions levels of imported versus domestic products thus requires complete lifecycle analyses of individual products and specific pairs of exporting-importing countries.

Government procurement policies that entail buy-local practices concerning climate-friendly goods and services have emerged as an issue under the principle of non-discrimination in the context of national economic stimulus programmes. The applicability of the WTO Agreement on Government Procurement to such trade issues is limited because many countries have not agreed to it; among those that have, there are many government agencies whose programmes are not covered (van Asselt et al., 2006; Hoekman and Kostecki, 2009; Malumfashi, 2009; van Calster, 2009).

Government subsidies for renewable energy and energy-efficiency goods and services have also become issues in relation to the WTO Agreement on Subsidies and Countervailing Measures, as well as the TRIMs agreement. Such issues have prompted WTO dispute cases, including one involving subsidies for producers of wind turbines (WTO, 2010) and another involving feed-in tariffs (WTO, 2011). The application of WTO subsidy rules could slow the development and diffusion of climate-friendly technologies, but it is not yet clear whether this has or will have an effect (see Bigdeli, 2009; Howse and Eliason, 2009; Howse, 2010 on subsidy issues).

There are WTO-related issues related to tariffs and non-tariff barriers resulting from climate change policy. In general, non-tariff barriers tend to be more important barriers than tariffs at the climate-trade interface, but tariffs are still high in some industries and countries (Steenblik, 2006; World Bank, 2008a). Countries may seek to limit competitive disadvantage introduced by domestic climate policy by raising tariffs and introducing non-tariff barriers that restrict imports, or by other BAMs. One example of a BAM would be a country that has imposed a domestic carbon tax also (1) imposing the carbon tax on imported goods and services at a rate proportional to the emissions associated with their production and (2) offering reimbursement to domestic exporters who sell a good or service outside of the jurisdiction of the carbon tax (Wooders et al., 2009; Elliott et al., 2010; Monjon and Quirion, 2011). Barriers to transfers of technologies identified by IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (IPCC, 2011) as potential contributors to climate change mitigation have been issues in the on-going WTO Doha Round negotiations (Tamiotti et al., 2009). Domestic subsidies such as those for biofuels have also been at issue in the Doha Round.

Border adjustment measures to offset international differences in costs—and thus possible international leakage (see Section 5.4.1) arising from international differences in mitigation policy—have become one of the most contentious and researched points of interaction (Babiker, 2005; de Cendra, 2006; Cosbey and Tarasofsky, 2007; Ismer and Neuhoff, 2007; Genasci, 2008; Frankel, 2008; Tamiotti and Kulacoglu, 2009; O'Brien, 2009; van Asselt and Brewer, 2010; Tamiotti, 2011; Zhang, 2012). This issue draws particular attention to differences between production-based and consumption-based emissions in both developed and developing countries (Figure 1.5 in Chapter 1). BAMs include policy options ranging from: (1) tariffs on imports or subsidies on exports based on the amount of GHGs released in their production to (2) 'compensatory measures,' as for instance the free-allocation emission permits in the EU ETS or export rebates to energy-intensive sectors. Theoretical arguments in favour of BAMs can be grouped into three classes, each discussed below: the reduction of economic inefficiencies in the context of an externality, the reduction of carbon leakage, and increasing participation and compliance in a climate agreement.

The economic research on BAMs stresses that the inclusion of more countries in climate policy, e.g., by linking permit trading schemes and including more sectors and countries, reduces economic inefficiencies relative to unilateral BAMs. While, BAMs can enhance the competitiveness of GHG- and trade-intensive industries within a given climate regime (Kuik and Hofkes, 2010; Böhringer et al., 2012a; Balistreri and Rutherford, 2012; Lanzi et al., 2012), welfare effects may be negative for consumers and countries facing BAMs on their exports. Overall welfare effects accounting for externalities are mainly perceived to be positive at an abstract theoretical level (Gros and Egenhofer, 2011); the evidence is more blurred at an empirical level and is sensitive to assumptions (The Carbon Trust, 2010; Fischer and Fox, 2012; Lanzi et al., 2012). Export rebates, the exclusion of energy and CO_2-intensive industries from regulation, or the free-allocation of permits to these industries are recognized as causing efficiency losses (Lanzi et al., 2012). Most empirical studies also do not confirm a need at the macroeconomic level for BAMs in the first place: they tend to find that climate policy is not a significant trade issue at the macro-economic level of national economies, though there are competitiveness and leakage issues for a few industries which are both GHG-intensive and trade-intensive. They hold that the main channel of impact of climate policies is through world energy prices and not through manufactured goods (Grubb and Neuhoff, 2006; Houser et al., 2008; Aldy and Pizer, 2009; The Carbon Trust, 2010).

The economic modelling literature on the effectiveness of BAMs to reduce carbon leakage finds that carbon leakage rates tend to decline by 2–12% following the introduction of a border adjustment tax (Böhringer et al., 2012a). The political literature on the appropriateness of using BAMs to address carbon leakage, on the other hand, tends to be divided into two perspectives. Developed countries and/or countries with some form of mitigation policy either already in place or considering this for the future argue that BAMs are necessary to avoid carbon controls driving production abroad. Arguments along this line have emerged in the European Union and the United States for instance (see Veel, 2009; The Carbon Trust, 2010; Fischer and Fox, 2012). Developing countries tend to oppose BAMs, as many are concerned about negative welfare effects for their countries and what they see as a violation of the principle of CBDRRC as agreed under the UNFCCC (Khor, 2010a; Droege, 2011a; Scott and Rajamani, 2012). Nevertheless, the technical difficulties of measuring production-induced or consumption-induced GHG emissions are significant (Droege, 2011a), and addressing them may be associated with high administrative costs, possibly outweighing the potential benefits (McKibbin and Wilcoxen, 2009).

Participation and compliance in climate agreements might be enhanced by BAMs. However, conceptual thinking on the question does not reveal a consensus, and direct evidence on the point is insufficient to reach definitive conclusions (see Barrett, 2003, 2009, 2010; Victor, 2010, 2011). Because BAMs affect the distribution of abatment costs across countires, enacting a BAM could result in welfare loss, particularly for exporting developing countries, and even retaliatory countermeasures (de Cendra, 2006; Mattoo et al., 2009; Böhringer et al., 2012b; Balistreri and Rutherford, 2012). For more discussion on the topic, see Section 13.3.3 on participation and Section 13.3.4 on compliance.

From the research on legal issues related to BAMs, four major conclusions emerge. First, BAMs may clash with WTO obligations, a point which is emphasized by many observers (Wooders et al., 2009; Condon, 2009; ICTSD, 2009; Holzer, 2010, 2011; Tamiotti, 2011; Du, 2011). Second, it is possible to design BAMs to be compatible with these obligations, according to other observers (Condon, 2009; Droege, 2011a; b), particularly when BAMs are targeted to countries based on their production technology efficiency (Ismer and Neuhoff, 2007). Third, WTO obligations and their legal interpretation have evolved over time, allowing for the possibility to bring trade and climate policy goals more in line in the future (Kelemen, 2001; Neumayer, 2004). Finally, the use of BAMs for climate change purposes may be politically controversial (Khor, 2010a).

A final WTO-related issue concerns the distinction between products and 'process and production methods' (PPMs). The legal notion of PPMs, as applied in the WTO, can be based on several aspects of production processes and can have a variety of effects on climate change-related policies. (For extensive discussions of the technical legal issues and their relevance to climate change issues see Cottier et al., 2009).

13.8.2 Other international venues

Two GHG-emitting industries that are centrally involved in international trade as modes of transportation are covered by separate international agreements outside the WTO system (see also Chapter 8). International aviation issues are covered by the Chicago Convention and the International Civil Aviation Organization (ICAO), while international maritime shipping issues have been addressed by the IMO (see Section 13.13.1.4 for performance assessments of the ICAO and IMO).

There has been increasing interest in recent years in both ICAO and IMO in industry practices concerning GHG emissions, with some efforts at international cooperation to address them. However, there has been international conflict about the European Union's inclusion of international aviation within the EU ETS. The Kyoto Protocol in Article 2.2 recognized ICAO as the venue for negotiations on matters concerning international aviation emissions, but in the absence of what was seen in the EU as adequate progress in the ICAO, the EU decided to include aviation in the EU ETS. This unilateral decision prompted strong reactions (Mueller, 2012; Scott and Rajamani, 2012), and flights in and out of the EU were temporarily exempted in April 2013 through the ICAO General Assembly scheduled for September-October 2013. Among the concerns expressed about the inclusion of aviation in the EU ETS has been the assertion that it represents a violation of the principle of CBDRRC of the UNFCCC (Scott and Rajamani, 2012; Ireland, 2012), though this concern only applies to developing countries. There are also legal issues about the relationship of the EU ETS to the Chicago Convention, which has traditionally been the international legal basis for aviation policies. Though studies indicate that the economic impacts of the EU ETS provisions are small relative to other airline expenses and ticket prices and that much of the cost can be passed on to consumers (Scheelhaase and Grimme, 2007; Anger and Köhler, 2010), political and legal issues have nevertheless made international cooperation difficult. The IMO (2009) concluded that a significant potential for CO_2 reduction exists through technical and operational measures, many of which appear to be cost-effective; the IMO adopted an energy efficiency design index (International Maritime Organization (IMO), 2011). A link of carbon controls of aviation and shipping to the EU ETS and/or a possible U.S. ETS is suggested by Haites (2009) with the view that carbon offsets under the CDM could also be used.

There are other international institutional contexts within which climate change-trade interaction issues have been addressed, namely, the World Bank, G8, G20, IEA, MEF, and OECD (Section 13.5).

13.8.3 Implications for policy options

In terms of WTO and/or UNFCCC involvement, there are logically four possible sets of options for institutional architectures at the multilateral level for addressing climate change-trade interactions: WTO-based, UNFCCC-based, joint UNFCCC-WTO, and stand-alone. In addition, there could be hybrid arrangements involving combinations of these four types. For instance, proposals for Sustainable Energy Trade Agreements (SETAs) could be addressed in a variety of venues (ICTSD, 2011).

Of the four options, WTO-based architectures have received the most attention in the literature. Alternatives include making revisions in existing WTO arrangements or undertaking new arrangements (Epps and Green, 2010). Possible changes in existing WTO arrangements include a 'peace clause' (Hufbauer et al., 2009) or waiver agreement (Howse and Eliason, 2009; Howse, 2010), whereby WTO members would agree—within some limits—not to challenge on WTO grounds, respectively, climate policies in general or climate-related subsidies in particular. An extensive list of other possible changes to existing WTO arrangements has been discussed by Epps and Green (2010), whose suggestions include: change GATT Article XX (which allows exceptions to members' obligations, including measures for the 'conservation of exhaustible natural resources') so that climate measures are explicitly identified as qualifying for exceptional treatment; add a similar provision to the Subsidies Agreement; change the burden of proof or standard of review for the scientific evidence presented in climate change cases to Dispute Settlement panels; change Dispute Appellate Body rules to take into account the scientific uncertainties in climate change cases; establish a notification process for members to inform other members of the adoption of climate policies with trade implications; and establish a Climate Change Committee, which could facilitate conflict resolution without resorting to the Dispute Resolution process.

Many possibilities for a new Climate Change Agreement at the WTO have also been discussed by (Epps and Green, 2010). The elements of such an agreement could include: establishment of a Climate Change Committee (as above); establishment of a notification procedure for climate change measures (as above); establishment of climate change mitigation as a legitimate objective; development of a 'non-aggression clause' that would prohibit unilateral actions, such as BAMs; adoption of transparency requirements for national climate change policymaking processes to determine their legitimacy in relation to climate change concerns and protect against disguised trade protectionism; adoption of environmental rationales for subsidies; reviews of members' trade-related climate measures to insure that they are substantive responses to climate issues; and clarification of the potential application of PPMs questions to climate change disputes. Although these ideas have been mentioned in the literature, they have not been formulated as specific proposals to the WTO.

UNFCCC-based options have been discussed in the literature (Werksman et al., 2009) relating to the possible creation of a 'level' playing field, such as through border charges on imports, or border rebates for exports, though views differ greatly, as indicated above in the discussion of BAMs.

A potential joint UNFCCC-WTO agreement has not yet received much attention in the published literature (Epps and Green, 2010). However, there are already in effect arrangements whereby the UNFCCC secretariat is an observer in meetings of the WTO Committee on Trade and Environment (CTE) and is invited on an ad hoc basis to meetings of the Committee overseeing the specific trade and environment negotiations (CTESS) (Cossey and Marceau, 2009). In addition, WTO Secretariat staff members attend the annual UNFCCC COP meetings. Finally, a stand-alone arrangement could be developed (Epps and Green, 2010), a possibility that has not yet been analyzed in the published literature.

There are numerous and diverse unexplored opportunities for greater international cooperation in trade-climate policy interactions. While mutually destructive conflicts between the two systems have thus far been largely avoided, pre-emptive cooperation could protect against such developments in the future. Whether such cooperative arrangements can be most effectively devised within the existing institutional architectures for trade and for climate change or through new architectures is an unsettled issue (Section 13.4).

13.9 Mechanisms for technology and knowledge development, transfer, and diffusion

Technology-related policies could conceivably play a significant role in an international climate regime (de Coninck et al., 2008). These policies have the potential to lower the cost of climate change mitigation and increase the likelihood that countries will commit to reducing their GHG emissions. By lowering the relative cost of more environmentally sound technologies, technology policy can increase incentives for countries to comply with international climate obligations and could therefore play an important role in increasing the robustness of long-run international frameworks (Barrett, 2003). Such policies might generate incentives for participation in international climate agreements by facilitating access to climate-change-mitigating technologies or funding to cover the additional costs of such technologies.

The role of international cooperation in facilitating technological change, including access to, facilitation of, and transfer of technology, is explicitly recognized in Article 4(1)(c) and (h), 4(5), 4(7), 4(8), and 4(9) of the UNFCCC. Article 4.5 states that "The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties…." The performance of international institutional arrangements and the adequacy of financing are subject to a variety of interpretations. (See Section 14.3.6.2 for a discussion of the UNFCCC CTCN, and see Section 15.12 for a discussion of financial issues.)

Although international technology transfer issues for climate change mitigation or adaptation have become concerns in numerous countries, these concerns have been especially acute in developing countries. Concerns over technology transfer in developing countries are frequently embedded in broader capacity building, sustainable development, and other equity issues (for discussions of the broader issues of CBDRRC and equity, see respectively Sections 13.2.1.2 and 13.4.2.4, and also Chapter 3 and Sections 4.1 and 4.2) (Brewer, 2008; GEA, 2012; Ockwell and Mallett, 2012).

Technology-oriented agreements could include activities across the technology life cycle for knowledge sharing, coordinated or joint research and development of climate-change-mitigating technologies, technology transfer, and technology deployment policies (such as technology or performance standards and incentives for technology development or adoption). International technology policy may play an important role in improving the efficiency of existing research and development (R&D) activities by increasing the international exchange of scientific and technical knowledge and by reducing duplicated R&D effort that could be shared across nations. (Newell, 2010a).

13.9.1 Modes of international incentive schemes to encourage technology-investment flows

Absent additional market failures, underinvestment in innovative activity relative to socially optimal levels can occur due to several well-understood general properties of innovation (see Section 15.6). At a global level, international carbon markets and the flexibility mechanisms they may employ, such as international linkage of domestic emission programmes, offsets, and the CDM, may be used to finance emission reductions in developing countries and transferring technology between nations and regions (see Section 13.13 and Haščič and Johnstone, 2011). Clear rules for these markets and their associated flexibility mechanisms may be established under international agreements and domestic policies to aid the removal of unnecessary barriers to technology transfer and to facilitate investment flows.

Because private-sector investments constitute more than 85 % of global financial flows (UNFCCC, 2007b), international trade and foreign direct investment are the primary means by which new knowledge and technology are transferred between countries (World Bank, 2008b). While domestic actions can improve the conditions to enable technology transfer investments (e.g., through regulatory flexibility, transparency, and stability), international actions can also contribute. In particular, the literature has identified tariffs and non-tariff trade barriers as impediments to energy technology transfer (World Bank, 2008b). An existing example is OECD regulation of export credits, with specific conditions to foster technology transfer for climate change mitigation (OECD, 2013).

In summary, national and supra-national policies that provide incentives for climate change mitigation will likely play an essential role in stimulating public investment, financial incentives, and regulations to promote innovation in the necessary new technologies for mitigation goals. Reducing fossil-fuel subsidies may have a similar effect (UNEP, 2008).

13.9.2 Intellectual property rights and technology development and transfer

The strength of IP right protection, together with other conditions related to the rule of law, regulatory transparency, and market openness affect technology transfer rates (Newell, 2010a) (see also Sections 3.11 and 16.8).

The goal of IP protection is to foster both the development of new technologies (innovation), and the diffusion of new technologies across countries (technology transfer) and within countries (technology adoption). In theory, such protection achieves these ends by increasing and/or maintaining the private economic incentive to create and transfer technology. At the same time, protection of IP also works to slow the diffusion of new technologies, because it raises their cost and potentially limits their availability. To the extent that IP protection raises the cost and limits the availability around the world of mitigation technologies, the potential for new technologies to reduce the cost of mitigation will be hampered. Concern by developing countries that IP protection for low-carbon technology will make climate action excessively costly has been a contentious issue in the climate negotiations (Government of India, 2013). On the other hand, IP protection may encourage firms to innovate more than they otherwise would, thus potentially increasing the supply and reducing the cost of new technology.

In order to balance the possible incentive effects of IP protection against the adverse impact of such protection on costs and availability, it is important to assess the empirical significance of the incentive effects, both with respect to innovation and technology diffusion. The empirical evidence regarding the effect of IP policy on innovation is discussed in Section 15.6.2.1.

Even if stronger IP protection does not foster creation and development of new technologies, it may be beneficial for mitigation if it fosters transfer of technologies from developed to less developed countries. Theoretically, strong IP protection in developing countries may be necessary to limit the risk for foreign firms that transfer of their technology will lead to imitation and resulting profit erosion. Looking at technology transfer in general, empirical literature finds a role for strong IP protection in receiving countries in facilitating technology transfer from advanced countries through exports, foreign direct investment (FDI), and licensing for transfers from the OECD (Maskus and Penubarti, 1995); FDI to 16 countries originating in the United States, Germany and Japan (Lee and Mansfield, 1996; Mansfield, 2000); and transfers from the United State (Smith, 1999). Regarding recipients, Awokuse and Yin (2010) find evidence for transfers to China, and Javorcik (2004) for FDI to 24 Eastern European transition economies. Branstetter et al. (2006) assessed FDI to 16 middle-income countries after those countries strengthened their IP protection and found indicators for United States technology transfer increasing subsequently.

The empirical evidence suggests that the effects of IP strength on technology licensing parallel those for FDI. The Branstetter et al. (2006) results discussed above included royalty payments among the measures of technology transfer that increased after IP strengthening. Smith (2001) finds that the association between strong IP and licenses is stronger than the relationship between IP and exports. In general, the evidence indicates a systematic impact of IP protection on technology transfer through exports, FDI, and technology licensing for middle-income countries for which the risk of imitation in the absence of such protection is relatively high. It is unclear whether or not these effects extend to the least developed countries whose absorptive capacity and ability to appropriate foreign technology in the absence of strong IP protections is less (Hall and Helmers, 2010). It is also important to note that IP rules are but one of many factors affecting FDI decisions. Others, particularly more general aspects of the legal and institutional environment that affect the riskiness of investments, may be more significant (Fosfuri, 2004).

Literature on the role of IP rights in the development of low-carbon technologies remains limited (Reichman et al., 2008). For example, Barton (2007) analyzes existing solar, wind, and biofuel technologies, and Lewis (2007, 2011) and Pueuo et al. (2011) find that IP protection has induced innovation in wind technologies without compromising technology transfer. However, problems could arise if new, very broad patents were granted that impede the development of future, more efficient technologies (though even then, IP rights may provide flexibility). Compulsory licensing has been proposed as a mechanism to encourage technology transfer. Such an action would compensate a patent holder while overcoming market power inhibitions on voluntary licensing (Reichman and Hasenzahl, 2003). Despite short-run technology transfer benefits, compulsory licensing of mitigation technologies may not be desirable in the long-run, and current international law may limit the circumstances under which compulsory licensing can be used to achieve climate change mitigation objectives (Fair, 2009; Maitra, 2010).

In summary, there is inadequate evidence in the literature regarding the impact of IP policy on transfer of GHG-mitigating technologies to draw robust conclusions. If the experience from other technology sectors is indicative, maintenance of effective protection of IP may be a factor in determining the transfer of mitigation technology to middle-income countries, although other aspects of the legal and institutional environments are likely to be at least as important. There is little empirical evidence that protection of IP rights is a major factor affecting technology transfer to the least developed countries.

13.9.3 International collaboration to encourage knowledge development

International cooperation on climate change mitigation has been linked to technology transfer policy, as transferring knowledge and equipment internationally, and ensuring that technologies are deployed in appropriate national contexts, may require additional international action (Newell, 2010a). International cooperation on climate-relevant technology policy can include efforts to share technological knowledge, collaborate or coordinate R&D, and directly facilitate and finance technology transfer.

13.9.3.1 Knowledge sharing, R&D coordination, and joint collaboration

International cooperation on knowledge-sharing and R&D coordination can include information exchange, coordinated or harmonized research agendas, measurement and technology standards, and coordinated or cooperative R&D (IEA, 2008; de Coninck et al., 2008; GEA, 2012). Examples of such existing forms of cooperation include the Carbon Sequestration Leadership Forum, the former Asia Pacific Partnership on Clean Development and Climate, the U.S.-China Clean Energy Research Center, and the International Partnership for a Hydrogen Economy. Empirically, a higher degree of collaboration has been more frequently observed in research areas of more fundamental science without larger commercial interests (for example, the ITER fusion reactor and the CERN supercollider) (de Coninck et al., 2008). In addition to enhancing the cross-border flow of scientific and technical information, joint R&D can increase the cost-effectiveness of R&D through complementary expertise and reduced duplication of effort (Newell, 2010a).

The IEA has coordinated the development of more than 40 Implementing Agreements. Under these agreements, IEA member countries may engage either in task-sharing programmes pursued within participating countries and funded by individual country contributions, or in cost-sharing programmes funded by countries but performed by a single contractor. All existing Implementing Agreements incorporate some degree of task sharing while about half incorporate cost sharing (Newell, 2010a).

13.9.3.2 International cooperation on domestic climate technology R&D funding

Public sector investment in energy- and climate-related R&D has decreased since the early 1980s, although there has been a relative increase in recent years (Newell, 2010a, 2011). Newell (2010a), using the precedent of European Union cooperation on setting R&D spending goals, has proposed an international agreement that would increase domestic R&D funding for climate technologies (either in absolute terms, percentage increases from historic levels, or relative to GDP) in an analogous fashion to internationally agreed emission targets. Also, at a G8 meeting, in the context of a consideration of how to address climate change, there was agreement to seek to double public investment in R&D between 2009 and 2015 (G8, 2009).See Torvanger and Meadowcroft (2011) and Fischer et al. (2012) on issues in the design and support of climate friendly technologies. International coordination of R&D portfolios may reduce the duplication of R&D effort, cover a broader technological base, and enhance the exchange of information gained through national-level R&D processes. This coordination could cover the allocation of effort by government scientists and engineers, the targeting of extramural research funding to specific projects, and public-private partnerships. Engaging developing economies in developing and deploying new technologies may require further technology development to meet the needs of domestic institutions and norms.

Bringing newly developed technologies to full commercialization often presents challenges, and for some technologies, such as carbon dioxide capture and storage (CCS) (de Coninck et al., 2009), the private sector may not have sufficient incentives to commercialize new technologies in the absence of international cooperation. Since some of the economic risk the private sector faces reflects uncertainty about the incentives that future climate policies would create, governments may have a role in financing technology demonstration projects (Newell, 2007). The case for such demonstration projects may be stronger in developing and emerging economies, where incomplete capital markets may undermine investment in commercializing these technologies.

13.10 Capacity building

Several articles in the UNFCCC (4.1(i), 4.5, 6 and 9.2(d)) and the Kyoto Protocol (Article 10(e)) acknowledge the role of capacity building in promoting collective action on climate change. While the texts give special attention to building capacity in developing countries, they also recognize a general need for all countries to improve policy, planning, and education on climate issues.

A variety of public, private, and NGO initiatives have undertaken capacity building efforts both within and outside of the UNFCCC, focusing primarily on three issues: (1) adaptation policy and planning; (2) mitigation policy and planning; and (3) measurement, reporting, and verification of mitigation actions. Capacity building efforts with respect to technology transfer are addressed in Section 13.9. Section 4.6.1 considers adaptive capacity and mitigative capacity jointly as dimensions of 'response capacity' and Section 15.10 considers capacity building in a national context.

Capacity building for adaptation includes (i) risk management approaches to address adverse effects of climate change, (ii) maintenance and revision of a database on local coping strategies, and (iii) maintenance and revision of the adaptation practices interface (Yohe, 2001; UNFCCC, 2009b). The process of preparing the National Adaptation Programmes of Action (NAPAs) for and by LDCs identifies their most 'urgent' adaptation needs. However, capacity building for adaptation is likely insufficient because the costs in such regards are rarely estimated (Smith et al., 2011; see also WGII, 3.6.4). At the community level, adaptation projects require time and patience and can be successful if they raise awareness, develop and use partnerships, combine reactive and anticipatory approaches, and are in line with local culture and context (Engels, 2008; Dumaru, 2010).

Capacity building for mitigation includes technical assistance and policy planning support. In CDM, capacity building has focused on the establishment of Designated National Authorities (DNAs), the training of private and public personnel, and project support (Michaelowa, 2005; Winkler et al., 2007; Okubo and Michaelowa, 2010). Efforts aimed at capacity building for NAMAs and REDD-plus are expected (Bosetti and Rose, 2011). NAMAs are a potentially important means of action by developing countries that emerged in the negotiations under the Bali Roadmap (UNFCCC, 2007); and have been assessed in the literature (Wang-Helmreich, et al., 2011; Upadhyaya,, 2012; Tyler et al., 2013). NAMAs are discussed in detail in Section 15.2.

Monitoring and evaluation activities are important to ensure effective implementation of a capacity-building framework, helping to understand gaps and needs in capacity building, share best practices, and promote resource efficiency (UNFCCC, 2009c). There are few empirical assessments of current capacity building approaches in relation to climate change (Virji et al., 2012).

13.11 Investment and finance

Since AR4, international cooperation on climate policy has increasingly focused on mobilizing public and private investment and finance for mitigation and adaptation activities. Such cooperation has included the setup of market mechanisms to generate private investment as well as public transfers through dedicated institutions (Michaelowa, 2012b). The Copenhagen Accord of 2009 included a provision to jointly mobilize 100 billion USD per year by 2020 to address the needs of developing countries, in the context of meaningful mitigation actions and transparency of implementation (UNFCCC, 2009a). In order to reach this goal, the High-level Advisory Group on Climate Change Financing (AGF) (AGF, 2010) identified four potential sources of finance: public sources (funds mobilized under the UNFCCC), development bank instruments, carbon market finance, and private capital.

In the follow-up to the Copenhagen conference, the term 'climate finance' has been coined for financial flows to developing countries, but there exists no internationally agreed definition (Buchner et al., 2011). Stadelmann et al. (2011b) provide a discussion of what could be counted and how the baseline for international climate finance could be set to provide 'new and additional' funds. See Section 16.2.2 for a description of the potential financing need and Section 16.5 for a description of possible public funding sources.

13.11.1 Public finance flows

13.11.1.1 Public funding vehicles under the UNFCCC

The largest share of UNFCCC-organized climate finance goes to mitigation: Abadie et al. (2013) provide reasons for this, such as the differences between mitigation and adaptation regarding public good characteristics and the lack of information regarding context-specific climate impacts. The UNFCCC mobilizes financial flows to developing countries and countries in transition through four primary vehicles: (1) the GEF, which focuses on mitigation (GEF, 2011); (2) the LDCF and SCCF, which focus on adaptation; (3) the Adaptation Fund, which also focuses on adaptation; and (4) the GCF, which will focus on both mitigation and adaptation when it becomes operational. The GEF is the secretariat for all funds other than the GCF. This section reviews the literature on these four mechanisms (see also Section 16.5; UNFCCC, 2012a).

The Adaptation Fund is financed through a 2 % in-kind levy on emissions credits generated by CDM projects, though parties to the Kyoto Protocol have contributed additional funding (Liverman and Billett, 2010; Horstmann, 2011; Ratajczak-Juszko, 2012). All other UNFCCC funding vehicles are based on voluntary government contributions that can be counted as official development assistance. Ayers and Huq (2009) maintain that the Adaptation Fund's governance structure avoids many of the issues of ownership and accountability faced by other funds. Harmeling and Kaloga (2011) examine the influence of competing interests on funding decisions by the Adaptation Fund Board. Under the Fund, Multilateral Implementing Entities (MIEs) have had the most success in securing funding, followed by National Implementing Entities (NIEs), but none by Regional Implementing Entities (RIEs). This disparity has led to calls for transparency in project assessment (Harmeling and Kaloga, 2011). Grasso and Sacchi (2011) discuss