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Climate change mitigation in high-income cities

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High-income cities face significant challenges in mitigating anthropogenic climate change; constraints exist in their evolution towards low-carbon urban systems due to their mature infrastructure, established energy sources and recent uncertainty in economic growth. The extent of these challenges depends on individual economic, social and environmental contexts. Seto et al. (2014) present four principal drivers of urban emissions in the Intergovernmental Panel on Climate Change's Fifth Assessment Report: economic geography & income, socio-demographic factors, technology and infrastructure & urban form. Given that these drivers vary substantially across urban areas in high-income cities, emissions per capita also differ (see Figure 1). However, regardless of context, deep emissions reductions in these cities are necessary.

High-income cities are principal drivers of energy consumption within their national boundaries. Grubler et al. (2012) estimate that over 80% of energy use in OECD90[1] countries took place in their urban areas in 2005. Moreover, Elzen et al. (2013) calculate that industrialized nations have contributed 52% of all emissions between 1850-2010, while having only hosted 26.7% of the global population during that time. These industrialized countries have undergone rapid urbanization in the past 60 years, with the United Nations (UN) (2014) suggesting that populations living in cities increased from 54.6% to 77.1% between 1950 and 2010. Cities in industrialized nations also enable much of the world's economic activity, with 380 high-income cities contributed to 50% of GDP in 2007 (Mckinsey Global Institute, 2011); GDP per capita has been shown to be correlate with GHG emissions (Kennedy, 2014). When considering energy demand, history of GHG emissions, high levels of urbanization and large economies, a case can be made that high-income cities are substantial contributors to climate change, supporting the call for their leadership towards a low-carbon future.

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[1] OECD90 includes countries in OECD Asia, Western Europe and North America

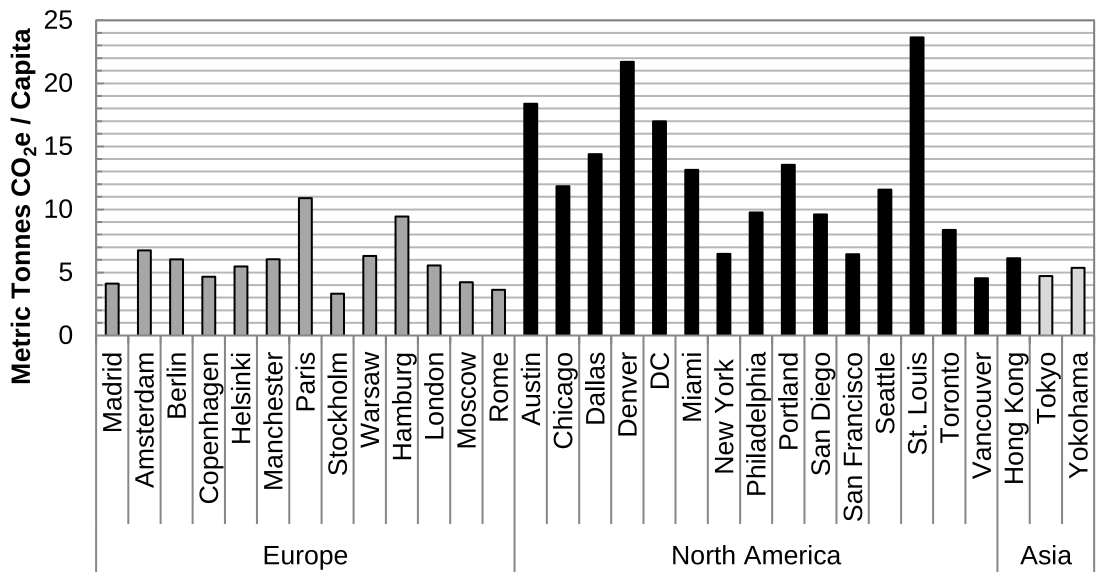

Figure 1: Per capita emissions for a variety of cities in industrialized countries (Source: CDP, 2012)[2].

Leadership in climate change mitigation at the municipal level has often matched or exceeded that at higher levels of government, especially in North America (Kennedy et al., 2012). With organizations such as C40 Cities and the US Conference of Mayors, as well as programs such as ICLEI's Cities for Climate Protection and Carbonn, municipal decision-makers have been able to share knowledge on best practices and develop initiatives that reduce greenhouse gas (GHG) emissions at the local level. In many cases, this approach has required supportive frameworks or programs from higher levels of government, though context-specific municipal policy has been an important component for action. This chapter provides a discussion of the challenges associated with GHG mitigation in high-income cities and current efforts to reduce their contribution to climate change.

1. Identifying the sources of emissions

The identification of major emitting sectors in cities is a critical first step towards mitigation, as this information can then be used to estimate the importance of the aforementioned four drivers of GHG emissions. The building (residential and commercial), transportation (passenger and freight) and industrial sectors differ in the types of secondary energy resources (and associated emissions) upon which they rely; cities have recognized the usefulness of their quantification and have identified strategies that will produce significant GHG emissions reductions. Figure 2 presents summaries of GHG emissions of eight cities within industrialized countries, while Figure 3 presents the annual emissions reductions they have achieved over a given timeframe (Kennedy et al., 2012). The absolute and per capita values of emissions in these cities are shown in Table 1. Annual reductions in emissions have been observed in each sector, with consistency found in the waste sector (albeit generally a small component of total emissions, as demonstrated in Figure 2). The greatest challenge lies with the transportation sector.

[2] It should be noted that the methodologies for GHG emissions inventories presented here use different allocation approaches as well as varying spatial and temporal boundaries. This explains some of the variation (see Ibrahim et al., 2012), though the trends are generally informative of development approaches within the regions above.

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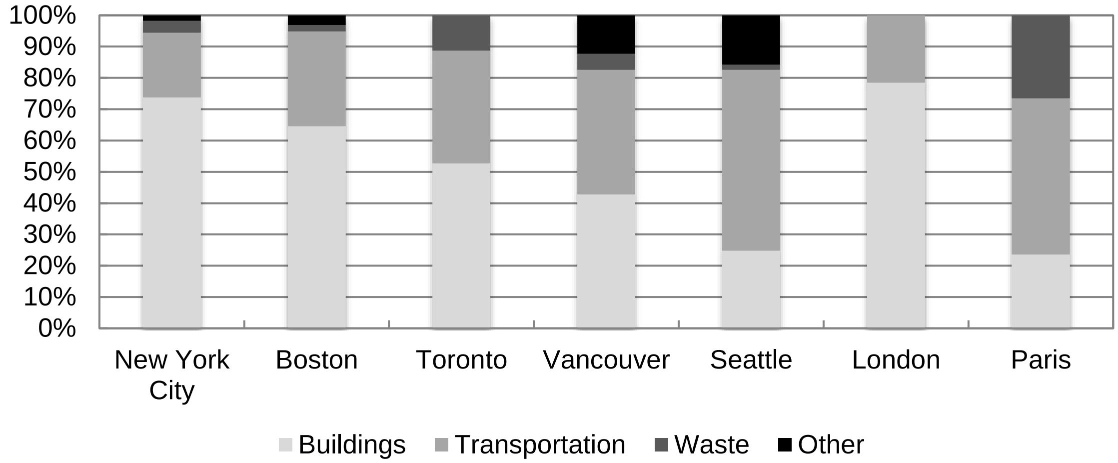


Figure 2: GHG emissions from eight high-income cities. Note that London is missing emissions for 'waste' and 'other', and Toronto is missing emissions for 'other'. Sources: PlaNYC, 2013a; City of Boston, 2013a; City of Toronto, 2013a; Government of British Columbia, 2014; Stockholm Environment Institute, 2014; City of London, 2014; City of Paris, 2011

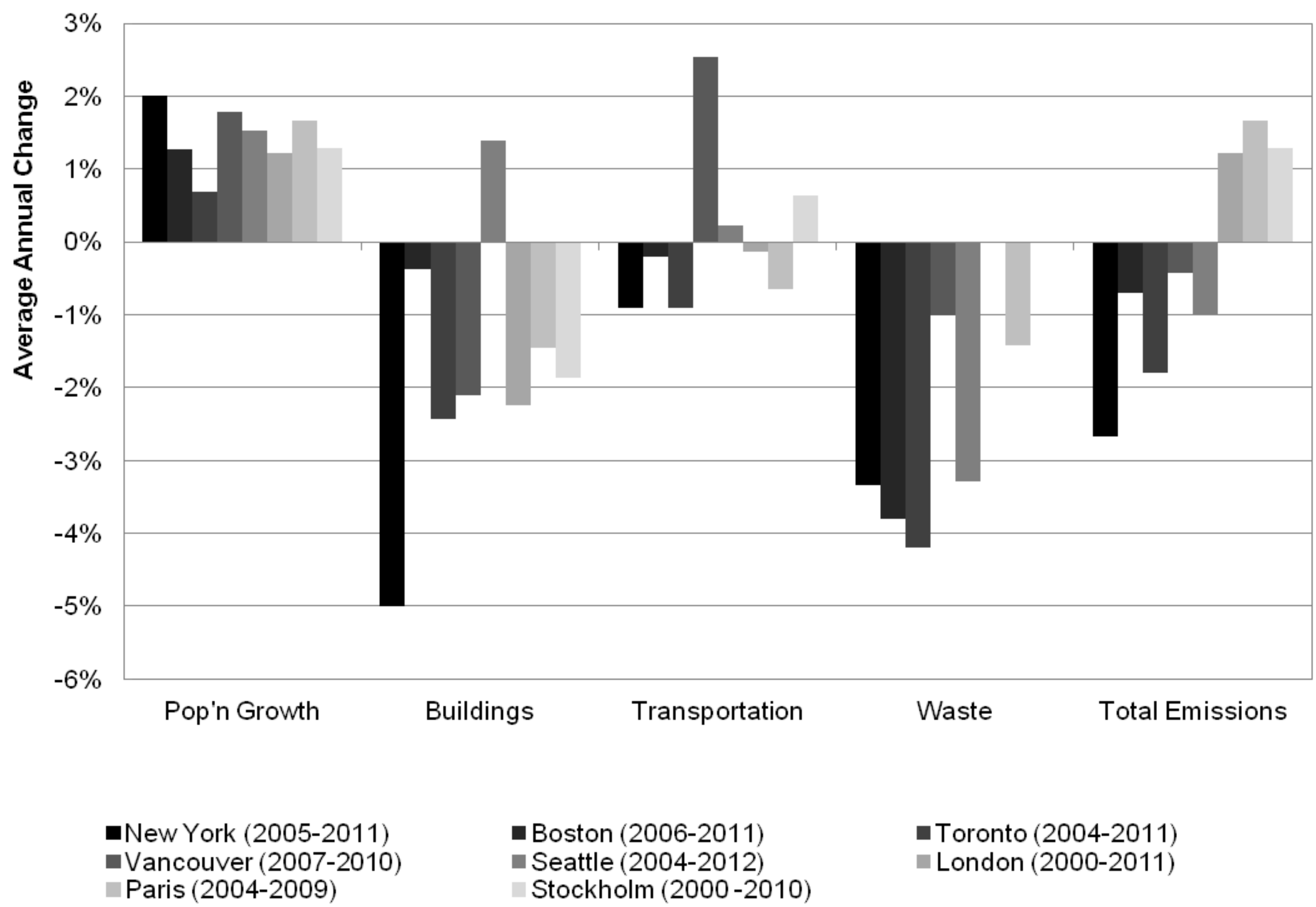


Figure 3: Annual population growth and average annual GHG reductions for eight high-income cities - averages are over the time periods displayed. Sources: PlaNYC, 2013a; City of Boston, 2013a; City of Toronto, 2013a; Government of British Columbia, 2014; Stockholm Environment Institute, 2014; City of London, 2014; City of Paris, 2011

Table 1: GHG emissions and reductions achieved from eight industrialized country cities. Sources: PlaNYC, 2013a; City of Boston, 2013a; City of Toronto, 2013a; Government of British Columbia, 2014; Stockholm Environment Institute, 2014; City of London, 2014; City of Paris, 2011

City (Inventory Year)	Population	GHG Emissions (tonnes CO_2e)	Average Annual Emission Reductions from Baseline* (tonnes CO_2e)			Baseline Year
			Buildings	Transportation	Waste	
Toronto (2011)	2,615,060	23,258,000	360,000	-40,500	155,000	2004
New York City (2011)	8,175,133	53,400,000	1,200,000	105,000	86,000	2005
Vancouver (2010)	642,843	2,646,000	13,000	-12,000	1,000	2007
Seattle (2012)	634,535	6,132,000	-23,000	-9,000	5,000	2005
Boston (2011)	625,087	6,767,000	25,000	4,000	7,000	2006
London (2011)	8,204,100	39,905,000	934,000	12,000	N/A	2000
Paris (2009)	2,274,880	31,851,395	87,000	172,000	7,000	2004
Stockholm (2010)	847,073	3,118,000	46,000	-7,000	N/A	2000

*negative reductions indicate an emissions increase in that sector

Although many urban areas in industrialized countries have been able to achieve some success with GHG mitigation, a challenge remains with existing, aging infrastructure (Kennedy et al., 2014; Kennedy et al., 2012; Hodson *et al.*, 2012). Building, transportation and energy infrastructure have been established based on the availability of low-cost sources of secondary energy that possess a relatively high energy density. Energy efficiency gains can lower energy demand substantially, but limitations on demand reduction are imposed by existing urban form and infrastructure systems, not to mention the rebound effect or Jevons paradox (i.e., some of the gain in efficiency is lost in demand increase) (Sorrell, 2007). If pressure increases for mature economies to provide a greater share of the global carbon budget to emerging economies, the legacy of this infrastructure imposes significant energy demands that must be met by low-carbon energy sources. The next section of this chapter describes the nature of the mature infrastructure challenge to high-income cities in more detail.

2. The challenges: Aging infrastructure and lock-in

Many cities in industrialized countries are currently experiencing major challenges with their aging infrastructure stock, which is not only based on the availability of fossil fuels but is also frequently in need of replacement (Federation of Canadian Municipalities et al., 2012; ASCE, 2013; Rockefeller Foundation, 2014). At some point in their history, these cities have either experienced prolonged periods of economic growth or urban renewal that led to the undertaking of substantial infrastructure development; many of these projects are now either reaching or passed the end of their design lives, in addition to being ill-suited to a low-carbon economy. This is notably the case for cities that rebuilt themselves after important events, such as the great fires of London in 1666 and Chicago in 1871 or the modernization of Paris in the second half of the 19th century. This is also the case for a number of cities that have witnessed tremendous growth or redevelopment after World War II.

The infrastructure systems and urban form of high-income cities have often arisen during eras of much different energy realities than those of today (Mohareb et al., 2015). Conversely, historic or older cities, which may exhibit urban forms that are more conducive to public transportation, for example, may be constrained (spatially, legally, culturally, etc.) in retrofitting the built environment for active transportation or high-performance buildings (Seto *et al.*, 2014; Ma *et al.*, 2012). In established cities that experienced much of their development in the 20th century, the urban form and infrastructural legacy of an automobile-centric era has resulted in low population densities (which are difficult to superimpose with effective active or public transportation infrastructure) and single family homes. Presently, as these periods of economic and population growth have waned in many cases, high-income cities are in a position where they lack the financial resources to maintain or renew this infrastructure; derelict and decaying urban expressways and neighborhoods in many North American cities serve as evidence.

Buildings stocks represent another example of challenges associated with aging infrastructure that varies according to location. Given that buildings are long-lived, and older buildings tend to have higher space conditioning energy demand per unit of area (Building Performance Institute Europe, 2014; Office of Energy Efficiency, 2013), a burden is placed on urban residents of older cities. Figure 4 demonstrates the building stock age observed in a number of industrialized countries and world regions. In all cases, much of the housing stock has been constructed prior to the 1960s; in the case of Northern and Western Europe, it is over 40%. In England, 56% of the housing stock was built before 1965, with over one third constructed prior to 1945 (Department of Communities and Local Government, 2015).

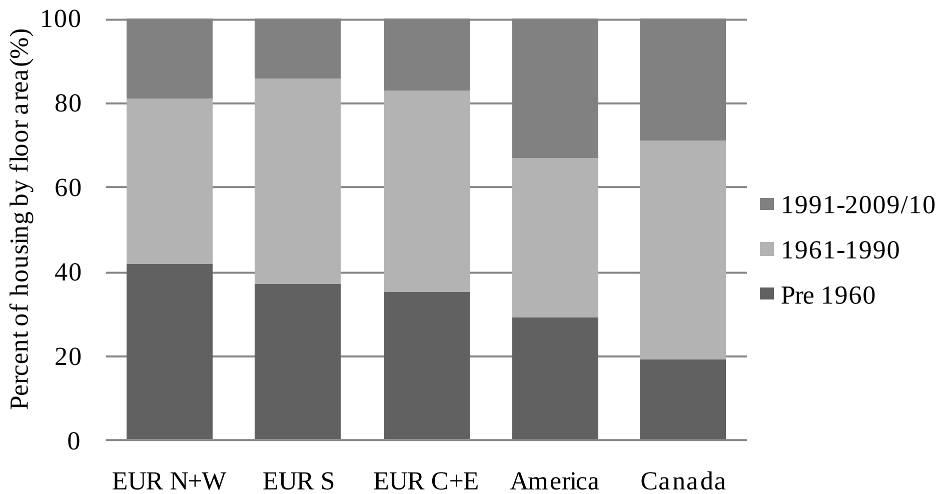


Figure 4: Distribution of residential housing stock by construction age for Europe and North America. EUR N+W: Finland, Ireland, Austria, Netherlands, Germany, France, Sweden, Denmark, United Kingdom; EUR S: Greece, Malta, Spain, Italy; EUR C+E: Estonia, Lithuania, Latvia, Hungary, Romania, Slovak, Slovenia, Poland, Bulgaria, Czech Republic. Sources: OEE, 2013 (Canadian data); EIA, 2013 (American data); and Building Performance Institute Europe, 2011 (European data). The Canadian estimates are from dwelling number counts assuming American floor space distributions.

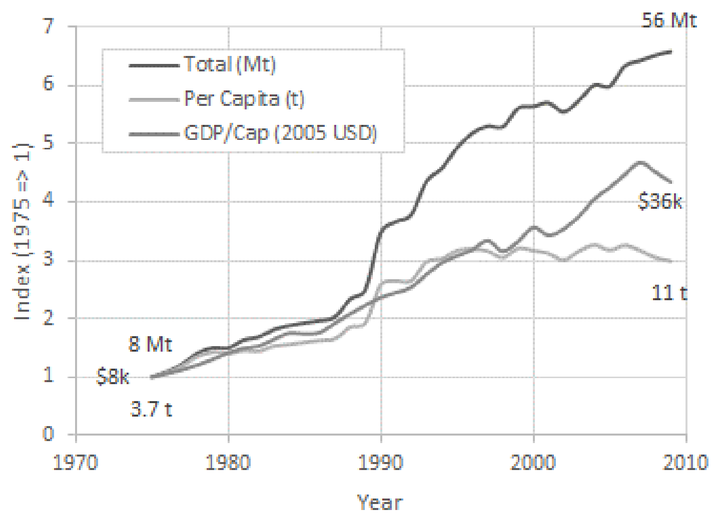
In addition, as integrated entities, aging infrastructure systems may unnecessarily burden one another. For instance, a water system in poor condition will require more electricity and may also structurally damage roads and buildings. This is the case in London (UK), where 30% of all drinking water supply distributed is lost in the ground because of leaky pipes (Kennedy et al., 2007).

Finally, this challenge extends beyond the simple replacement of infrastructure. Indeed, coupled with consistent urban growth, increasing environmental concerns and a society with constantly evolving needs, current infrastructure must be redesigned and adapted to contemporary challenges. At the moment, much hope falls within the general concept of the 'smart city' that has become popular (Allwinkle &

Cruickshank, 2011; Grob, 2010), although it remains to be formally defined. With the advent of sensors, a 'smart city' is often illustrated with features such as smart energy and water meters or with the use of new technologies for travel demand management purposes. The extent to which these smart initiatives can assist in broadly reducing GHG emissions remains unclear, however, especially since these initiatives tend to provide the data upon which decisions can be made, as opposed to directly lowering energy usage.

Transitions of Urban Centers' GHG Emissions – The Unique Case of Singapore

It is revealing to consider how the sometimes generic and often radically unique context of Singapore's development affected its emissions over the last four decades (See below; World Bank, 2013). Singapore's development, similar in economic and physical form to many other cities, is characterized by an increasing use of energy as affluence and population rose. Like some, but not as many would be hoped, the effect on GHG emissions of this increasing energy usage was mitigated by an increasingly cleaner energy supply mix. Since the 1990s Singapore's emissions from electricity and heat production has been in decline. Many developed cities of a similar population do not have as much GHG intensive industry but are also not as tightly constrained geographically, which limits energy-intensity of the urban form (see discussion in the section "Spatial and Land Use Planning" below). In Singapore, the carbon benefits from densification are at least partially offset by the land reclamation efforts. The industry mix and density are quite the opposite of many of larger North American cities, for example, that tend to eschew heavy industry as they develop and have the 'luxury' of space resulting in lower density development. The case of Singapore is remarkable for the pace of its development and its recent decoupling of emissions from population and economic growth. However, there are many possible paths for the urban development. Will there be just as many paths for urban GHG mitigation?



3. Urban approaches to GHG mitigation

Urban governments have long understood that cities, being the foci of future population and economic growth, must leverage their power to begin the market transformation towards decarbonization. While it has been noted that the ability for municipalities to influence the reduction of GHGs in some sectors requires the assistance of higher levels of government, there is a great deal that can be accomplished at the urban scale (Arup & C40 Cities, 2011; Seto et al., 2014, p. 34). While higher levels of government may be politically constrained in their mitigation policy (or simply unwilling to take action), municipal governments are able to take appropriate measures at a scale that reflects the will of their electorate

(Lutsey & Sperling, 2008). As pointed out by Seto et al. (2014), a city's greatest leverage in reducing GHG emissions is at the 'meso' scale, such as policies to improve the efficiency of the municipally-owned building stock or improving the level of service of public transportation. Municipalities also operate at a more manageable scale than national or state levels for the systemic solutions inherent in most mitigation measures, such as the integration of land use and transportation planning or resource recovery (Grubler et al., 2012). Additionally, cities have direct influence over a number measures that will be key to the long term emissions reductions necessary to meet the target of 2°C of warming (such as land use planning, public transportation systems or waste management) (Seto *et al.*, 2014).

Urban economic systems also have the potential to be much more resource efficient in their functioning when compared with rural areas. Cities are often the focal points of a nation's economic growth, providing incubators for new ideas and drawing together actors that can leverage their specializations to greater effect through collaboration (Jacobs, 1970). Given the proximity that arises through the increasing population density (stimulated by the increasing returns to scale that is typically observed), cities can find greater economic, infrastructural and energy efficiencies in serving their inhabitants (Carlino, Chatterjee & Hunt, 2007; Bettencourt, Lobo, Helbing, *et al.*, 2007). In addition, politically-attractive co-benefits of GHG mitigation exist at the urban scale, such as improved urban environments through greenery (aesthetics and comfort [Pikora et al., 2003; Rosenzweig et al., 2009]) as well as reduced health impacts of fossil fuel consumption (Harlan & Ruddell, 2011). For a more detailed discussion on urban greening and associated health benefits see Trundle & McEvoy in this volume.

The energy, building, transportation and municipal sectors have all been targeted through financial incentives, regulatory measures and direct investment. Prominent measures that have been taken in high-income cities are described below. It is important to point out that a multitude of mitigation options are available to cities within the industrialized world, with certain measures proving more successful than others. Kennedy et al. (2014) demonstrate how urban characteristics, such as population density and electricity grid emissions intensity, can be used in the development of infrastructure strategies that provide the most effective mitigation. For example, in a low-density city such as Los Angeles, focusing on the decarbonization of the electricity grid coupled with the electrification of transportation (including electric vehicles) will likely result in lower transportation sector emissions than focusing on the expansion of public transportation options. Other characteristics, such as land use mix, connectivity, climate (heating or cooling degree days), housing stock composition, industrial sectors characteristics and infrastructure age, must also be examined, in order for a city to identify the drivers of its emissions.

3.1 Energy

Given that most cities in industrialized nations have a long-standing reliance on fossil-based sources of primary energy, municipal governments have identified opportunities to reduce GHG emissions through encouraging the growth of renewable energy. This approach is particularly effective in cities in the industrialized world, since energy prices are often a relatively small component of disposable income, making them good candidates for early adoption of emerging renewable energy technologies (which have yet to reach grid parity with other electricity generation). A list of sample programs in North American, European and Australian cities are presented in Table 2.

A number of mechanisms can be applied to accelerate the transition to low-carbon energy sources, including financing, direct municipal investments or legal mandates. Considering financial approaches, Property Assessed Clean Energy (PACE) programs provide a means to tie expenditures on renewable energy to the property itself (rather than the investor). Additionally, the upfront costs can also be avoided by providing the option of payment installments, which can, in turn, be based on actual cost savings realized (i.e., a 'pay-as-you-save' plan). The benefits of such schemes can reach beyond mitigation; one study estimates that four million USD in spending on PACE programs in the US has the potential to create ten million USD in economic output, one million USD in tax revenue and 60 jobs (ECONorthwest, 2011).

Direct municipal investments or purchase can include those made by the city or by its associated utilities. Cities, such as Houston, TX, purchase a fraction of their total energy demand of the municipal operations in equivalent renewable energy certificates (RECs). Conversely, the utility provider in the City of Brussels awards green certificates (similar to RECs) to local small scale producers of solar power, so that these certificates can then be sold on the open market (Energuide, 2013). An alternative to green certificates is 'white certificates', which can be credited to a utility customer based on reductions in energy demand (Transue & Felder, 2010). Additionally, investments in infrastructure, such as combined heat and power plants, improve the efficiency of energy provision and reduce associated GHG emissions. In the case of Vaxjo, Sweden, the firing of such a plant with biomass, along with biomass-fired district heating plants, has resulted in an estimated reduction of 76% in GHG emissions from residential heating between 1993-2005 (City of Vaxjo, 2007). Switching from fossil sources to biomass can provide additional mitigation, though considerations of forest carbon recovery and feedstock must be made (McKechnie et al., 2011).

Regulations also provide valuable tools to reduce GHG emissions in the energy sector. Requirements for renewable energy installations on new developments (e.g., Lancaster, California) improve local expertise in installations and create a broader market for low-carbon energy. These can also provide incentive to reduce energy demand; the Merton rule promotes both renewable energy technologies and lower total energy demand for a building, as lower demand facilitates fulfilling the requirement of meeting 10% of energy needs with on-site renewable energy generation (Merton, 2013). Feed-in tariffs provide an incentive for low-carbon energy development based on price certainty for producers that wish to sell to the grid. Some care/flexibility should be applied to ensure that a net carbon emissions reduction is actually achieved in a given jurisdiction, as renewable alternatives can increase emissions upstream (e.g. manufacture) or onsite (e.g., additional concrete for structural integrity) or have a long-term carbon payback (e.g., biomass); these may not completely offset those associated with conventional alternatives, especially as low-carbon options diffuse into the energy supply.

Table 2: Municipal actions in established cities to mitigate GHG emissions in the energy generation / supply sector

Initiative	Description	Further Reading
Renewable energy financing	Payments are made through property taxes, eliminating upfront costs that can frequently act as a barrier to investment, while alleviating concerns around reclaiming retrofit costs during the sale of a property. Sacramento's Property Assessed Clean Energy represents one of the largest programs to allow financing of renewable energy and efficiency retrofits to both commercial and residential properties.	PACE Now, 2013
Municipal renewable energy certificate	Numerous cities set purchasing requirements for RECs, supporting regional initiatives for renewable power	City of Houston, 2013

(REC) purchasing requirements	generation. Houston, TX will purchase 50% of its electricity between 2013-2015 through RECs.	
District energy and combined heat and power generation from biomass	Centralized energy systems have the potential for energy efficiency improvements relative to distributed systems, due to improved equipment sizing and load balancing. District heating systems provide a more efficient fuel means to provide space heating energy services, with an estimated energy-use savings of 10-20% (Harvey, 2010; section 15.3.2). Vaxjo, Sweden produced 53% of its energy from renewable sources (predominantly biomass) in 2010, using district energy plants for both heating and electricity - over 80% of heating demands were met through renewable energy sources.	City of Vaxjo, 2011
Renewable energy requirement for new construction	Popularized by the London borough of Merton, council requires that 10% of new commercial buildings over $1000m^2$ generate 10% of their energy needs onsite. Barcelona requires that 60% of hot water in new, renovated or repurposed buildings be supplied by solar hot water. The City of Lancaster, California became the first city in the US to require all new construction projects to incorporate solar PV as of 2014. The requirement specifies that 0.5-1.5kW be produced per unit constructed, depending on lot size and location.	City of Lancaster, 2013
Smart meters	To encourage electricity peak shaving, many municipal and regional electric utilities (such as those in Melbourne, Australia) require the installation of smart meters. These meters transmit energy demand for a given consumer at regular intervals throughout the day, allowing for appropriate price signals to be sent during peak demand (which is often supplied by carbon-intensive energy).	Government of Victoria, 2013
Feed-in tariffs	In order to incentivize renewable energy development, many municipalities offer feed-in tariffs through their municipal electric utilities. Los Angeles' Department of Water and Power, as one example, intends to allocate 100 MW of generation to local small and large scale solar power producers.	City of Los Angeles, 2013

3.2 Buildings

Buildings generally represent a significant opportunity to mitigate GHG emissions in established cities; much of the existing stock has been built to standards that are not only far below the level of energy performance required to achieve significant reductions in global GHG emissions, but also fall well short of current building codes due to their age. Municipal approaches have aimed to improve the GHG performance of new buildings (through building code revisions) and existing buildings (through regulations or subsidizing/financing of retrofit options) as well as to increase public awareness of the measures that can be taken to reduce demand. To make any substantial impact, however, current buildings will have to go through 'deep' retrofits, which can lower energy by more than 50%, in contrast with 'shallow' retrofits that amount to 10 to 30% decrease (Lucon et al., 2014).

Improving energy literacy of businesses and residents is an important step being taken by many cities of the industrialized world. For example, San Francisco, Boston and New York City require regular reporting of energy consumption from large commercial buildings; this creates awareness of energy consumption, engagement with energy benchmarks within communities and encourages action to reduce energy costs. Moreover, the implementation of energy feedback systems in the residential sector improves the appreciation of behavior and technologies that can reduce energy costs as well as GHG emissions.

All levels of government have provided subsidies for energy efficiency upgrades within the building sector through rebate programs as an economic instrument towards market transformation (Lucon et al., 2014). However, uncertainty exists in the effectiveness of the provision of direct subsidies through rebate programs; free-ridership, rebound effects and financial burdens can impact the magnitude of energy savings from rebates (Galarraga et al., 2013). A summary of actions taken in the building sector is provided in Table 3.

Table 3: Municipal actions in established cities to mitigate GHG emissions in the building sector

Initiative	Description	Further Reading
High-energy performance standards for municipal building codes and ordinances	In an effort to improve the energy performance of new construction, some cities (such as Dallas and San Francisco) have developed more rigorous building codes than those enacted by higher levels of government. For example, Toronto's 'Green Standard' requires a significant energy efficiency improvement to low-rise residential buildings two years prior to the adoption of the same standard by the provincial government. Builders attaining an even higher level of building performance were provided with a 20% reduction in their development charges. Additionally, ordinances are being implemented that require more rigid energy efficiency standards for new construction (numerous municipalities in Illinois; Dallas, TX), properties undergoing significant retrofits (Berkeley, CA) and properties being sold (San Francisco, CA). In Germany, cities including Frankfurt, Leipzig and Hamburg require that new public buildings adhere to the Passive House standard (since 2007, 2008 and 2012, respectively); meanwhile, Freiburg has made the same requirement for all residential buildings since 2011. The City of Brussels has responded to the European Union's Energy Performance of Buildings Directive by mandating that construction and retrofits of residential, office and school buildings align with the Passive House standard as of January 2015.	City of Toronto, 2013b; City of Boston, 2013b; City of Berkeley, 2013; City of San Francisco, 2013a; NREL, 2009; Passive House International, 2014
Addressing split incentives between tenants and property owners	Benefits to improve energy efficiency of rental units are often either realized by the renter (in the case where the tenant pays utility bills), reducing the incentive for property owners to improve the energy performance of these units.	Williams, 2008; Hsu, 2014

	Cambridge, MA is one jurisdiction attempting to remedy this issue, through the provision of draft 'green leases', which allow increases in rental charges that amount to less than the expected savings in energy costs. Additionally, requiring energy bill information to potential tenants is another approach to addressing the split incentive, as is required in the European Union and various US jurisdictions such as Seattle and New York City.	
Mandatory certifications	Energy efficiency is an important component of internationally-recognized green building certification systems. Cities, including Chelmsford, UK and Boston, MA, have recognized this (as well as the numerous other benefits related to productivity and property value) and now require that certain new developments meet Building Research Establishment Environmental Assessment Methodology (BREEAM) and Leadership in Energy and Environmental Design (LEED) standards, respectively. Additionally, smaller towns have also taken this approach for the residential sector, such as the Town of East Gwillimbury, Canada, which requires a national energy efficiency standard for all new residential construction.	Chelmsford City Council, 2013; City of Boston, 2013b; Federation of Canadian Municipalities, 2013.
Indirect and direct energy feedback systems	This approach informs the energy end-user on how their energy consumption compares with their historic usage and with the usage of their neighbors. Jurisdictions in Illinois and Minnesota have realized significant reductions in energy demand (6% and 2%, respectively), primarily by equipping their residents with more information on their energy use.	Allcott, 2011; Harding & McNamara, 2013
Incentives for high-performance construction	Municipalities have also begun to provide incentives for developers that aim to exceed existing building codes and municipal buildings standards. These incentives include expedited approvals for developers or reduced development charges (numerous cities in California as well as Toronto).	City of Toronto, 2013b; State of California, 2010; Passive House International, 2014
Property-tied renewable energy or energy efficiency financing	In addressing the barrier imposed by high upfront costs of investments in GHG mitigation, municipalities and utilities offer financing for technologies that is linked to the property. This financing can take the form of pay-as-you-save billing (Toronto) or a long-term arrangement where a small charge is regularly applied to property tax or utility bills (such as Berlin's Energy Saving Partnership or Property Assessed Clean Energy in various US jurisdictions).	City of Toronto, 2013c; C40 Cities, 2007; PACE Now, 2013
Energy audit subsidies or requirements	Cities have been able to provide basic energy audits for commercial and industrial buildings either at a subsidized	City of Seattle, 2013;

	rate or free of charge (Seattle). Additionally, certain cities have mandated audits upon sale (Austin) or at a particular frequency (San Francisco) as well as benchmarking (Boston and NYC) of annual energy consumption, with the potential to improve the monitoring and analysis of energy consumption toward reducing demand. The City of Stockton, CA has set retrofit targets; if targets are not met by 2013, energy auditing will be mandatory for all home sales or when building permits exceeding 1,200 USD are issued.	BuildingRating, 2014; ACEEE, 2013; City of San Francisco, 2013b; City of Stockton, 2013
Municipal carbon trading	Large cities may be able to direct resources to reduce building energy demand through a regional cap-and-trade scheme. Tokyo's cap-and-trade program (including facilities in its industrial and commercial sector) was able to realize a 13% reduction in GHG emissions (roughly 1.4 Mt) in its first year of operation.	Tokyo Metropolitan Government, 2012

3.3 Transportation

High-income cities, especially in North America and Australasia, exhibit urban forms that are generally dependant on private automobiles to provide transportation services (Newman & Kenworthy, 1989). However, facilitating the transition to low-carbon transportation technologies has the potential to substantially reduce this, with an estimate for a low-density North American city suggesting an 80% reduction is possible by 2050 (Mohareb & Kennedy, 2014). As observed in Figure 3, GHG emissions reductions in transportation are slower than in other sectors, given the slow turnover of the vehicle stock (the median vehicle service life in the US for cars and light trucks manufactured in 1990 was 16.9 and 15.5 years, respectively [Davis et al., 2013]), the length of time to complete public transportation projects (from inception to operation) and the relative inelasticity of transportation demand (Havranek et al., 2012). Additionally, considering the current low mode share of public transportation, a substantial shift from private passenger vehicles to public transportation would require substantial investments in new infrastructure, in order to make a significant reduction in vehicle trips (Engel-Yan & Hollingworth, 2008). Finally, approaches to encourage shifts to active modes of transportation (i.e., walking, cycling) are generally in the form of large scale urban (re)development projects, with results that are observed in the long-term.

Attempts to either develop public transportation systems that can operate effectively within these constructs or reduce the carbon intensity of existing modes of transport have been made in many high-income cities. The US has experienced a surge in public transportation investment over the period between 1995-2012, with increases in capital funding from federal, state and municipal governments of 131%, 108% and 179%, respectively (APTA, 2014); this amounted to annual capital funding of 17.billion USD in 2012. These transportation modes have a significant energy and carbon benefit; for example, Poudenx and Merida (2007) suggest trolley buses and light rail transportation are eight times more energy efficient than personal vehicles, per passenger kilometre traveled. Additionally, enabling the evolution of markets for alternatively-fueled vehicles through greening the municipal fleet or encouraging the adoption of electric vehicle infrastructure paves the way for long-term reductions in GHG emissions. Efforts to address travel behavior are also important, with a notable approach having been taken in the London borough of Sutton. Rewards (lotteries and gifts) are used to encourage active transportation; transportation planning advice and encouragement of travel planning is also provided to schools, businesses and residences (Borough of Sutton, 2010).

Ultimately, a concerted approach between transportation and urban planners is required to reduce the energy and GHG emissions associated with urban transportation. This is particularly important in cities expecting continued population growth. Infill development with mixed uses and transit-oriented design are also important components of long-term transportation emissions reduction strategies. A summary of prominent transportation-related actions taken in high-income cities is provided in Table 4.

Table 4: **Municipal actions in established cities to mitigate GHG emissions in the transportation sector**

Initiative	Description	Further Reading
Investments in public transportation	Significant investments in public transit have the potential to reduce emissions through shifting transportation-mode shares from automobiles to buses, light rail and subways. Los Angeles, London and Madrid are all examples of cities investing in meeting transportation demand through public transit. Madrid estimates that its subway system emits 50.73 g CO_2e / passenger-km (compared to a Spanish 2015 model year passenger vehicle average of approximately 84 g CO_2e / passenger-km [European Commission, 2014; European Environmental Agency, 2010 - uses 2010 estimate for occupancy]).	TRCA, 2010; Metro Madrid, 2013
Intelligent transportation systems	Improving the efficiency and information systems of a transit network can boost ridership by providing a more reliable and attractive alternative to private automobiles. Innovations such as bus tracker systems and transit signal priority are examples of how these behavior changes can be promoted.	Zhang et al., 2011
Pedestrianization & improved cycling infrastructure	Pedestrianization of many streets in Europe or in Times Square in New York City shift the convenience of using motorized transport to active transport. Focusing on cycling infrastructure has a similar impact (e.g., Copenhagen), with the ability to address longer trip lengths (such as commuters). Additionally, bicycle sharing programs make active modes of transportation available and convenient for use for point-to-point trips.	New York, City, 2013; City of Copenhagen, 2011
Vehicle share programs	Zurich was the first city to host a car-sharing program in 1948 (Selbstfahrergemeinschaft), with many European cities experimenting since then and burgeoning into other global cities with greater success. Car shares have the potential to reduce upstream GHG emissions embodied in vehicles by reducing the total number of vehicles purchased as well as providing an indirect road-pricing approach to vehicle usage. Cities have assisted in these programs by providing parking spaces for these vehicles	Shaheen & Cohen, 2007

	(such as Dailmer's Car2Go model in many North American and European cities).	
Electric vehicle (EV) charging infrastructure	In jurisdictions with low-carbon electricity grids, the installation of EV charging infrastructure has the potential to mitigate community transportation GHG emissions. The presence of charging stations encourages the adoption of EVs, increasing visibility and reducing range anxiety associated with these technologies. Some jurisdictions that lead the adoption of electric vehicles include Amsterdam and Copenhagen.	Hydro Quebec, 2013; New York Times, 2013; State of Green, n.d.
Low-emission municipal fleets & taxis	Many municipalities demonstrate leadership in converting their own vehicle fleets to hybrid electric vehicles and other lower-emissions vehicles. Additionally, numerous cities (e.g., Hong Kong, Barcelona and New York City) encourage electric vehicles in private taxi fleets. Taxis are ideal candidates for EVs since they mostly operate in central business districts, where congestion allows the exploitation of recursive breaking and sufficient density of charging stations is easier to attain. Some cities (Reykjavik, Oslo and Stockholm) also opt to use biofuels (some of which are sourced from municipal solid waste feedstocks) for their municipal fleets.	CFM, 2010; Nordic Council of Ministers, 2012
Parking charges & road pricing	Incentivizing lower-carbon modes of transportation or carpooling by increasing the price of automobile usage and increasing its convenience is a common approach to reducing congestion. Parking prices are frequently set in cities to disincentivize automobile usage, presumably reducing vehicle emissions as well. The imposition of road pricing mechanisms in various cities (e.g., Singapore, Stockholm and London) has been shown to be effective in reducing congestion and, by extension, its related GHG emissions. Pay-as-you-drive insurance provides another means to price vehicle kilometers traveled, reducing travel behavior (increasingly available through insurance providers).	TRCA, 2010
High-occupancy vehicle (HOV) lanes & bus-on-shoulder (BoS)	HOV lanes and BoS transportation represent relatively low-cost approaches to improving public transit services. These address congestion and any associated GHG emissions from the net decrease in fuel consumption.	TRB, 2013

3.4 Municipal services

Emissions reductions from municipal activities provide leadership for the broader community, in addition to necessary participation in the early stages of a local market transformation to low-carbon technologies, services and behaviors. By adopting more efficient or alternatively-powered vehicles, buildings, street lighting, or water and wastewater treatment and distribution operations, municipalities reduce their emissions and raise awareness of the importance of mitigation. Given the permanence of most municipal operations, investments in measures with longer-term payback periods also become easier to justify (e.g., deeper building retrofits) (Arup & C40 Cities, 2011). Municipalities use GHG inventories of their operations to identify the most significant opportunities to reduce both costs and emissions. In addition to approaches taken in municipally-operated transportation and buildings (described in previous sections), options for mitigation are discussed here.

Cities have relatively greater influence in controlling GHG emissions from waste. Dependence on sanitary landfills for waste disposal in many North American municipalities has led to a legacy of methane emissions (a GHG that is 34 times more potent in its radiative forcing than CO_2 over a 100-year time horizon) (Myhre et al., 2013), which would not have been released otherwise had these materials degraded in the presence of oxygen. Furthermore, substantial GHG emissions occurring outside municipal boundaries can be mitigated through recycling and waste prevention (USEPA, 2006). A number of approaches have been taken to reduce these, ranging from simple source reduction to end-of-pipe treatment methods. A common example of the latter has been to capture landfill gas and either flare it or utilize it for electricity or heat generation. Cities such as Toronto, Canada have realized significant emissions reductions from capture and utilization. Additionally, by diverting biogenic carbon from landfills, some cities have been able to use waste as a resource to a greater degree by digesting this waste in bioreactors, producing a valuable soil amendment and more efficiently producing biogas (City of Toronto, 2009).

Waste-to-energy facilities are more commonly used in Europe, and cities in the region have recently employed more sophisticated approaches to improve energy yield and offset emissions elsewhere. For example, Copenhagen's waste-to-energy operations provide enough energy through its district energy system to meet the demands of 70,000 homes (DAC, 2014). The city also plans to divert more plastics (i.e., fossil carbon) from their incineration waste stream, which is estimated to reduce emissions by an additional 100,000 t CO_2e towards their goal of carbon neutrality by 2025 (City of Copenhagen, 2009). Additionally, biogenic carbon treated in wastewater treatment plants has also been exploited for its energy potential; in the case of the City of Stockholm, biogas from its wastewater treatment process is refined and utilized in its public transit buses (Baltic Biogas Bus, 2012).

Other municipal responsibilities (from administrative buildings to street lights) also present opportunities to reduce expenses and address climate change. Looking at street lights, cities in various industrialized nations have recognized the value in replacing high-pressure sodium lighting with light-emitting diode (LED) technology. The City of Halifax, Canada has planned the replacement of its street lights with LEDs, with projected annual savings of 120,000 CAD and 1000 t CO_2e (City of Halifax, 2011). A summary of measures undertaken are provided in Table 5.

Table 5: Municipal actions in established cities to mitigate GHG emissions in the government services sector

Initiative	Description	Further Reading
Source-separated organics	In order to prevent the release of methane from landfill operations and improve the diversion of waste, source-separated organics programs have been implemented.	City of Toronto, 2009
Landfill gas capture	Capturing methane produced by organic waste deposited in landfill sites is pursued to both reduce emissions and provide for a relatively clean source of renewable energy. As an	Government of Hong Kong, 2013

	example, Hong Kong displaces naphtha consumption by utilizing landfill gas in the production of electricity and heat.	
Wastewater biogas capture & Sludge management	Anaerobic digestion of wastewater sludge provides an opportunity for energy generation (biogas) and GHG mitigation. This biogas can be used within a facility or externally to meet heating or electricity needs.	Baltic Biogas Bus, 2012
Waste prevention	Programs to address residential and non-residential waste are using outreach and disincentive programs to reduce the amount of waste that is being generated. For example, studies on pay-as-you-throw programs in the Czech Republic and Sweden find that these initiatives resulting an 8% and 20% reduction in waste sent to the landfill, respectively, compared to jurisdictions without these programs.	Arup & C40 Cities, 2011; Dahlén & Lagerkvist, 2010, European Commission, 2008
High-efficiency traffic lights & street lighting	Replacement of high-pressure sodium lighting with LED technology provides significant savings in GHG emissions, costs and maintenance.	City of Halifax, 2011
Innovative waste-to-energy	Though traditional waste-to-energy through incineration are common globally, innovative approaches that can convert solid waste to advanced biofuels are supported in many high-income cities (British Airways' GreenSky project in London; Enerkem in Edmonton, Canada; transportation fuels in multiple Nordic cities).	British Airways, 2012; Enerkem, 2014; Nordic Council of Ministers, 2012

3.5 Land Use and Spatial Planning

Many developed cities face significant barriers to GHG mitigation imposed by their urban form. As touched upon in the transportation section, urban expansion since the early twentieth century has often relied upon low-density growth with segregated land uses. This land use and spatial planning approach is characterized by high transportation energy demand, low floor area ratios and greater floor area per housing unit (Seto et al., 2014; Peiravian et al., 2014). Improvements in land use and spatial planning can go a long way towards breaking free of the energy dependency observed in the other sectors discussed above. However, in this sense, developed cities are disadvantaged relative to those in the early stages of infrastructure growth; altering emissions intensities associated with the transportation and building sectors of established low-density, single-use urban areas requires a long-term vision, where infrastructure and development plans are well aligned with improvements in the urban form that are inherently lower carbon.

Seto et al (2014) describe four principal elements of land use and spatial planning that require consideration towards the long term goals of transportation demand reduction and intensification. These are density, land use, connectivity and accessibility. Achieving sufficient emissions reductions while reducing congestion requires consideration of these in relation to one another. For example, redeveloping a neighborhood in a low-carbon city must aim to improve residential/commercial density, increase the diversity of work/recreational opportunities available to them, incorporate finer grain blocks (to improve form for connectivity/walkability) and considerations of connectivity (for example, low-carbon transportation modes allowing access to the CBD). One study concluded that efforts to double residential density, increase employment density, improve the mixture of land uses, and encourage public transportation alternatives could reduce vehicle miles traveled per household by as much as 25% (National Research Council, 2009).

Table 6: : Municipal actions in established cities to mitigate GHG emissions in land use and spatial planning

Initiative	Description	Further Reading
Smart growth or Compact City policies	Developed world cities have attempted to reverse the low-density development patterns of the twentieth century through development charges that fees that better reflect the infrastructure costs of different development types, and through the creation of strict zoning constraints to curb sprawl.	Lu et al, 2013; Council of Capital City Lord Mayors, 2014
Mixed use development	Zoning strategies have been implemented in many cities to prevent further segregation of land uses. Some prominent examples of encouraging mixed land use include Singapore and Vancouver.	Walsh, 2013; Urban Redevelopment Authority, 2014
Major regeneration or infill projects	Infill and regeneration exploit the increased property values of derelict industrial sites in close proximity to central business districts in developed cities, while encouraging lower carbon building and planning approaches. Some prominent examples include Hammarby-Sjostad in Stockholm, Sweden and Newstead and Teneriffe in Brisbane, Australia.	Hammarby-Sjostad, 2014; Council of Capital City Lord Mayors, 2014
New urbanism / transit-oriented design	New urbanist building and neighbourhood designs are increasing in their uptake, with nearly 300 developments listed in the Congress for New Urbanism's (CNU) project database as of in April, 2015. These types of developments incorporate high-density, mixed-use and public/active transportation components, with potential for mitigation of building and transportation sector emissions. The CNU provides information on projects located around the world, including Brisbane, Baltimore and Berlin.	Congress for New Urbanism, 2014
"Complete street" design & promotion	Streets that make room for the safe participation of all modes of transportation have been increasingly encouraged in recent decades, in addition to the advancement of segregated infrastructure. Prominent examples of complete street designs in developed cities include Copenhagen and Seattle.	Smart Growth America, 2010; McCann, & Rynne, 2010; Woodcock et al. 2014

3.6 Bottom-up initiatives

Many bottom-up initiatives on urban GHG emissions mitigation are taking place in European, North American and Oceanic cities. These are often promoted by community renewable energy co-operatives, not-for-profit organizations and neighborhood groups. Due to the authors' experiences, this section explores examples of such bottom-up initiatives from the Toronto, Canada area. Toronto's waterfront is the site of the first co-operatively owned and operated urban wind turbine in the province. This 600 kW turbine is estimated to offset the needs of around 800 homes annually, and has been operating since 2002. This initiative has since expanded to develop other turbines and a number of solar energy co-operatives, which allow members to purchase bonds in solar projects that are backed by government feed-in tariff programs.

Another form of bottom-up initiative is led by non-profit community action groups. One such group in Toronto, called Project Neutral, has been conducting carbon footprint surveys of homes in Toronto in 2012-2013. The project initially targeted two neighborhoods through community-led efforts, with the specific goal of eventually retrofitting these neighborhoods for carbon neutrality. The hope is that a repeatable model of urban neighborhood retrofit for carbon neutrality can be developed. Thus far, there are a number of achieved successes, including the completion of hundreds of household surveys to establish baseline emissions levels, the creation of several online tools for reporting household and neighborhood improvements and creation of a tool to help achieve carbon emissions improvements (Project Neutral, 2014; Naismith, 2014).

Year-on-year, the two pilot-selected neighborhoods show decreases, except for single detached homes in one of the neighborhoods. This increase, however, may be because additional households joined in 2013, but are not differentiated in the reporting. Households outside of the pilot neighbourhoods are allowed to fill out surveys, but do not receive the extra direct guidance and support of the initial neighborhoods, such as the facilitation of neighborhood members going door-to-door to raise awareness. The survey respondents outside the pilot neighborhoods, however, show reductions. The findings are encouraging, and in time, it will be possible to assess trends with more depth and hopefully correct for factors such as changing weather.

Together the co-operative and the community action groups share at least three things in common: (1) they were developed by dedicated citizens concerned with climate change; (2) they have benefited from a number of strategic partnerships with governmental and non-governmental organizations in the region; and (3) they have early-on identified financial sustainability as an organizational need for success in achieving their mission.

3.7 Top-down Initiatives

There are also examples of cities and regions in the industrialized world that have taken a 'master planning' approach to low-carbon urban design. These new developments often include highly-efficient housing, considerations for either public transportation or low-carbon transport and on-site renewable energy generation. Some prominent examples are provided in Table 6.

Table 6: Sample urban (re)development projects that include measures to achieve substantial GHG emission reductions

	Key Characteristics and Challenges to Success	Further Reading
Hammarby Sjostad, Stockholm, Sweden	Hammarby-Sjostad, an urban redevelopment project on a former industrial site, has received considerable attention for its well-integrated district- and building scale renewable energy systems. Some key challenges to	Pandis Iveroth et al., 2013 Hammarby-Sjostad, 2014.

	the further adoption of additional alternative energy systems are the concerns they pose to the economics of existing energy infrastructure systems and the interference through the monopoly of the energy retailer.	
Beddington Zero Energy Development (BedZED), and One Brighton, UK	Completed in 2002, BedZED is a long-standing example of a low-carbon greenfield development. Providing 100 homes and workspace for 100 jobs, the original plan was for the neighborhood's low energy demand to be met through on-site biomass combined heat and power (CHP) system. However, given the small scale of this operation, maintenance requirements rendered this approach uneconomical. Following BedZED, One Brighton was constructed to apply the lessons learned from BedZED, and suggested that houses in this community achieve a 60-80% reduction in GHG emissions relative to a typical UK home. Other lessons learned from the project include the importance of making low-carbon lifestyles more convenient through design; the co-benefits of improved community cohesion; the value of energy service companies; and discussion of 'green facilities management' at the design stage.	BioRegional, 2014 BioRegional, 2009. BioRegional, 2002.
Masdar City, UAE	Featuring its own PV array complemented by roof top panels, a concentrating solar plant, short streets that are cooled by a large wind tower, driverless electric vehicles and sensor-controlled buildings, Masdar is an example of an attempt to create a new, low-carbon city in an arid climate. Major challenges have included the seclusion of the site, the high proportion of commuters and inability to attract sufficient foreign investment to boost employment.	Wired, 2013; Deutsche Welle, 2013
PlanIT Valley, Portugal	Endorsed by the Portuguese national government and the municipality of Paredes, this eco-city with a project population of 225,000 is intended to be an incubator for low-carbon innovation. Enhanced building monitoring, grid-connected vehicles and other intelligent infrastructure systems will rely on millions of sensors to optimize their performance. Observers state concerns about how this type of top-down control system for an urban environment will adapt to the complexities of a working city.	Salon, 2012; Living PlanIT, 2014.
Songdo, South Korea	Hosting branches of four overseas universities, Songdo ultimately hopes to house 75,000 residents and be the destination for 300,000 commuters. Active	Songdo, 2014; World Finance, 2014; Shwayri, 2013

transportation will be a key focus, with networks of cycle paths and pedestrian routes as well as an integrated underground waste collection system, which will supply a share of the site's energy needs. The district, which is planned to obtain LEED certification for neighborhood development, is facing early challenges in attracting businesses and investors to populate its office space as well as receiving criticism for the destruction of unique wetland ecosystem and high eco-premiums that exclude low-income/low-revenue residents and businesses.

While these approaches can demonstrate the best practices for new construction and serve as valuable case studies for low-carbon development, their relevance to reconstruction of existing buildings in established cities is limited. Reducing emissions in developed countries by 2050 on the order of 80% from 1990 levels, as suggested by the Gupta et al. (2007; Box 13.7), necessitates deep retrofitting of existing building stock.

3.8 Addressing both adaptation and mitigation

Many high-income cities have recently recognized the need to adapt to climate change, given the consensus on the increased frequency of severe weather events on vulnerable urban populations (Zimmerman & Faris, 2011). When it comes to mobilizing political capital to address climate change, there is some concern that adaptation measures may take precedence over mitigation measures (Gore, 2013). The concern arises since adaptation measures, whose benefits are local, clearly targeted and can be directly observed (often without the need to make the politically-charged argument for the threat of climate change), are more saleable than mitigation measures, whose impacts are globally distributed and may lack popular support in some jurisdictions. Put another way, local measures that address adaptation-related concerns can readily be seen functioning in their purpose of insulating against moderate and extreme weather events. Meanwhile, mitigation strategies that address a city's GHG emissions appear as a drop in the atmospheric ocean where increasing radiative forcing is altering the climate; as a result, successful mitigation requires the elusive (up until now) cooperation of an unwieldy group of international actors, in order to observe any effect (which will be over the long term and escape the notice of most urban inhabitants). This can make budgeting for adaptation strategies a politically safe approach for any municipality, especially where hard infrastructure is highly visible and can be appreciated regardless of one's perspective of humanity's role in the changing climate. As the impacts of climate change worsen, this potential dichotomy could be exacerbated.

The disproportionate role of industrialized nations in changing the composition of the atmosphere is illustrated by den Elzen et al. (2005), with nearly 80% of fossil energy CO_2 emissions between 1890-2000 attributable to industrialized (and former Soviet) nations. Additionally, many of the cities that are most vulnerable to extreme weather events are in earlier stages of economic growth, where per capita GHG emissions are relatively low compared with those in industrialized nations (Hallegatte et al., 2013; Dhakal, 2009; Sugar et al., 2012). Hence, mitigation activities may not be perceived as urgent in locations where the adaptation needs are most acutely felt. Stern (2006) demonstrates that while adaptation is necessary, the costs of mitigation are much lower than the recovery from severe weather events, and adaptation expenditures may not be equitably borne by those contributing to climate change. Therefore, efforts for adaptation and resiliency should be in addition to mitigation efforts, not in their place.

Some studies show that mitigation and adaptation issues can be addressed simultaneously through certain strategies, with prominent examples including improved building energy performance, expansion of urban forests and renewable energy systems (Sugar et al., 2013; Harlan & Ruddell, 2011; Laukkonen et al., 2009; Kennedy & Corfee-Morlot, 2012; Hamin & Gurran, 2009). While there may be more urgency for low- and middle-income cities to focus on the measures that address both sides of the climate change conundrum (see the Lwasa chapter in this volume for this discussion), high-income cities with (typically) greater financial resources should lead in the early experimentation and deployment of mitigation measures.

4. Conclusion

In order to meet long-term global targets for GHG emissions reductions, cities in the industrialized world require the replacement of energy service technologies, as well as the infrastructure and urban form that enable these. Many of these cities are providing exemplary pathways for initiating the transition to low-carbon systems, while others have created entire developments that are able to operate with minimal fossil energy inputs. There remains much to be done within municipal boundaries, especially with respect to existing building stocks that require deep retrofits to facilitate the use of low-density forms of energy that are intermittent. Moreover, while a radical change in transportation infrastructure is difficult, future land use planning policies may greatly contribute, notably by encouraging mixed use plans that favor active modes of transportation. With the combined efforts of top-down approaches from all levels of government, bottom-up approaches to reductions can support mitigation projects and help high-income cities provide the leadership required of them in moving towards a low-carbon global economy.

Ultimately, detailed regional long-term planning and monitoring are required for high-income cities to achieve deep reductions in their GHG emissions. A price on carbon is an essential component to effectively drive market transformation to low-carbon systems. New low- and zero-carbon energy systems must replace existing carbon-intensive systems. Sprawling developments must be reimagined, in order to support low-carbon lifestyles. Continued strengthening of leadership at the municipal level is central to this effort, in order to properly understand and implement the most effective options for mitigation in specific urban contexts. More research and experimentation at the city scale is required to achieve deep, permanent emissions reductions, in order to surpass what can be achieved by targeting low-hanging fruit.

While many jurisdictions have exhibited leadership, numerous others have been hindered by the absence of political will and, even more threatening, the funding gap observed between infrastructure needs and public funds. Broad, durable acceptance of the scope and onus of mitigation requirements that rests with the industrialized world is necessary for significant action. Even more fundamental is a consistent approach to GHG quantification across all cities, to identify successful, scalable mitigation strategies though comparable, longitudinal data (employing methodologies such as the WRI/ICLEI/C40 Cities Global Protocol for Community Scale Emissions). Once stable global leadership is in place, cities can play their prominent role in guiding their residents, and indeed the world, towards a low-carbon future.

Chapter Summary

- Progress is being made in many high-income cities in mitigating GHG emissions, including in all major emissions sectors.
- High-income cities face the additional challenges of having established infrastructure, uncertain future economic growth and entrenched values that inhibit political will to rethink urban systems.
- Emissions-reduction strategies within cities of the industrialized world span across sectors for energy provision, buildings, transportation, municipal services and land use and spatial planning.
- Concerns remain as to whether these reductions can be maintained for the long term or if they are merely addressing low-hanging fruit with politically attractive co-benefits, in addition to the added demands for adaptation.
- Comprehensive frameworks for emissions reductions need to be incorporated at the city level.

Research Needs

- Broad undertaking of longitudinal urban GHG quantification in cities of all scales and in all regions is needed, using a consistent methodology and with an effort to identify which emissions are locked-in and how this can be addressed.
- Deeper understanding of the future GHG implications of current infrastructure decisions and redevelopment options for the city are needed at neighborhood- and street-scales along with an understanding of how to make these adaptable to mitigation solutions on the horizon.
- Further exploration as to the extent to which urban mitigation and adaptation activities have complementary goals, as well as a broader quantification of the co-benefits of mitigation measures.

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