The contribution of urban-scale actions to ambitious climate targets

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Abstract

New and continued efforts are needed to strengthen and extend the ambition of current national pledges to reduce greenhouse gas (GHG) emissions and to close the gap between the current emissions pathway and a trajectory consistent with a 2-degrees Celsius target. In this working paper, we argue that cities have an important role to play in deepening the ambition of global climate targets. Cities have unique and strong influence over several policy levers – from urban planning to public transportation – that make them critical actors in reducing GHG emissions, avoiding further carbon lock-in, and decreasing the cost of future abatement. We find that urban actions could decrease global GHG emissions by 3.7 Gt CO_2e annually from a reference scenario in 2030, rising to 8.0 Gt CO_2e in 2050, with the greatest reductions arising from deep improvements in residential building energy efficiency and from a transition to efficient public transport for personal urban mobility. Realizing the full potential of these actions would involve bold and swift action by the world's cities, and would be aided by new sources of finance and national policy support. At the same time, because few of the actions considered here are explicitly currently included in national pledges, realization of this abatement could help extend the ambition of current pledges, or help nations deepen new commitments currently under consideration. Even greater reductions could be possible if cities were to demonstrate low-carbon

lifestyles for categories of consumption not covered by this analysis, such as product purchasing and food consumption.

1. Introduction and overview

Nations of the world have agreed to work towards limiting global warming to 2 degrees C above pre-industrial levels. Doing so will require staying within a strict "carbon budget" (IPCC 2013). So far, national pledges (e.g., those made under the Cancun Agreements) to reduce emissions have not yet put the world on a pathway consistent with this target (UNEP 2013). As a result, continued and new efforts are needed to strengthen and extend the ambition of current pledges, in order to close the gap between the current pathway and a trajectory consistent with the 2 degree target.

In this working paper, we argue that cities have an important role to play in deepening the ambition of global climate targets. Cities have unique and strong influence over several policy levers – such as urban planning and public transportation – that make them critical actors in reducing GHG emissions, avoiding further carbon lock-in, and decreasing the cost of future abatement (C40 Cities 2013; Blok et al. 2012; Seto et al. 2013; GEA 2012). Here, we quantify the global GHG reduction potential of urban action over the next few decades, finding that urban actions may decrease global GHG emissions by 3.7 Gt CO_2e from a reference scenario in 2030 and 8.0 Gt CO_2e in 2050.

National policymakers can use this information to place greater emphasis on the role of cities, and thus help inform and strengthen their national GHG reduction contributions. City policymakers can use the findings to inform the type of actions that may have the greatest global impact.

This paper details the potential of urban action in three "core" sectors – buildings, transport, and waste – and quantifies the GHG abatement potential of each. It closes with conclusions concerning the actions with the most significant abatement potential, and points to the need for further national and local action to help unlock this potential.

2. Approach – the *urban action scenario*

We present an *urban action scenario* that explores the extent to which urban policies and programs may help reduce global GHG emissions over the next few decades. Broadly speaking, we apply a "bottom up" scenario analysis framework, an approach commonly used in GHG abatement literature (IPCC Working Group III 2014; IEA 2013; GEA 2012). It first involves developing a reference scenario of the future economy, energy patterns, and urban GHG emissions in the absence of aggressive urban action, while considering recently adopted national policies, such as vehicle efficiency standards in China, the EU, and the US. This reference scenario is the "baseline" from which we assess the potential emission reduction opportunities of urban action, such that abatement potential in each year is the difference in emissions between the reference and *urban action* scenarios.

Very few assessments of global urban GHG emissions have yet been conducted, and there is no comprehensive, consistent data set of urban GHG emissions (Seto et al. 2013). Existing assessments can differ substantially in what they consider "urban", chiefly because of differences in defining urban boundaries and in what emissions "scopes" are considered. Even fewer analyses have considered how global urban GHG emissions may evolve in the future. As a result, our analysis is novel, in that it is one of the first attempts to construct a "baseline" assessment of future urban global GHG emissions and abatement, and based on a consistent accounting of urban GHG emissions sources over which local governments can exert greater influence (described further below). Of course, the assessment is also limited, in that the lack of comprehensive urban-scale data necessitates the use of a number of national, rather than urban-scale, sources. Most notably, our reference scenario draws heavily from the highly respected and widely used *Energy Technology Perspectives* series of the International Energy Agency (IEA 2014), which constructs alternative scenarios of how energy and GHG emissions may evolve in major world regions and economic sectors through 2050. We rely directly on IEA's characterization of future trends for widely-used technologies, such as appliances, lighting, and personal and freight vehicles, under the assumption that these technologies are not substantially different in cities than they are in the remainder of each country. For other technologies and energy drivers, however, we either adjust IEA's estimates[1] or look to other, urban-focused research, such as that by the Global Buildings Performance Network, GBPN (Ürge-Vorsatz et al. 2012) and the Institute for Transportation and Development Policy, ITDP (Replogle and Fulton 2014).

From this *reference scenario*, we develop the *urban action scenario* by applying a set of aggressive technologies and practices to curb urban energy use and greenhouse gas emissions. However, there is rarely a clean line between what is an "urban" action and what is not. Some policies and measures, such as bus and metro systems and land use planning, are squarely (and uniquely) in the hands of cities and other local government partners. Other policies and measures, including ones aimed at improving building energy efficiency, are implemented at both local and national levels, often with shared responsibility for achieving targets or standards. There are also those policies and measures that have historically been pursued largely at the national or in some cases state or provincial levels (e.g., those aiming to affect the fuel mix of electricity production or the efficiency of vehicles), though cities are showing increasing interest in some of these, including local licensing requirements or incentives for higher vehicle efficiency and local efforts to transition to less carbon intensive electricity. For the purposes of this analysis, we consider "urban action" to be any GHG emissions reduction associated with the following:

- **urban building energy use,** due to building energy codes, standards, and retrofit programs or requirements, including for lighting and appliances, as well as provision of district energy or incentives for solar PV, in both residential and commercial buildings;
- **urban passenger transport**, whether due to land use planning for compact urban form, expansion of public transit, measures to improve vehicle efficiency (including electrification), or transport demand and flow management (such as variable speed zones and better signal timing);
- **urban road freight transport**, due to better urban freight logistics management, and measures to increase urban road freight vehicle efficiency; and
- **urban waste management,** due to increasing waste collection, recycling, and landfill management for methane capture.

Urban policymakers have unique and strong influence over these "core" sectors, especially through the policies and measures listed above, even as national policies may complement or support local action.

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[1] For example, we start with IEA's characterization of residential building heating energy per person at the national or regional level, and adjust it based on the estimated heating demand in each city (as heating-degree days) relative to the population-weighted average heating degree days of the nation or region modeled by IEA. We also adjust IEA's overall building energy estimates to reflect the understanding that electricity use is predominantly urban, whereas use of traditional biomass is more predominantly rural (IEA 2010).

As for the reference scenario, we draw assumptions for technologies and practices applied in each of these sectors from the IEA (IEA 2014), GBPN (Ürge-Vorsatz et al. 2012), ITDP (Replogle and Fulton 2014), and a number of other, urban-focused studies (Grubler and Fisk 2012; Cambridge Systematics 2009; Hickman and Banister 2014).

We conduct our analysis for all urban areas considered in the United Nations' *World Urbanization Prospects 2011* (UN 2011).[2] This includes over 600 urban agglomerations with recent (2010) populations of at least 750,000 (totaling 1.5 billion), each of which we model individually, plus several thousand smaller urban areas that we divide into several world regions and model in aggregate (totaling 2 billion people). The total urban population covered is 3.6 billion in 2010, rising to 5.0 billion in 2030 and 6.3 billion in 2050. (For further details of our methodology, including urban population by city size and region, see the Appendix.)

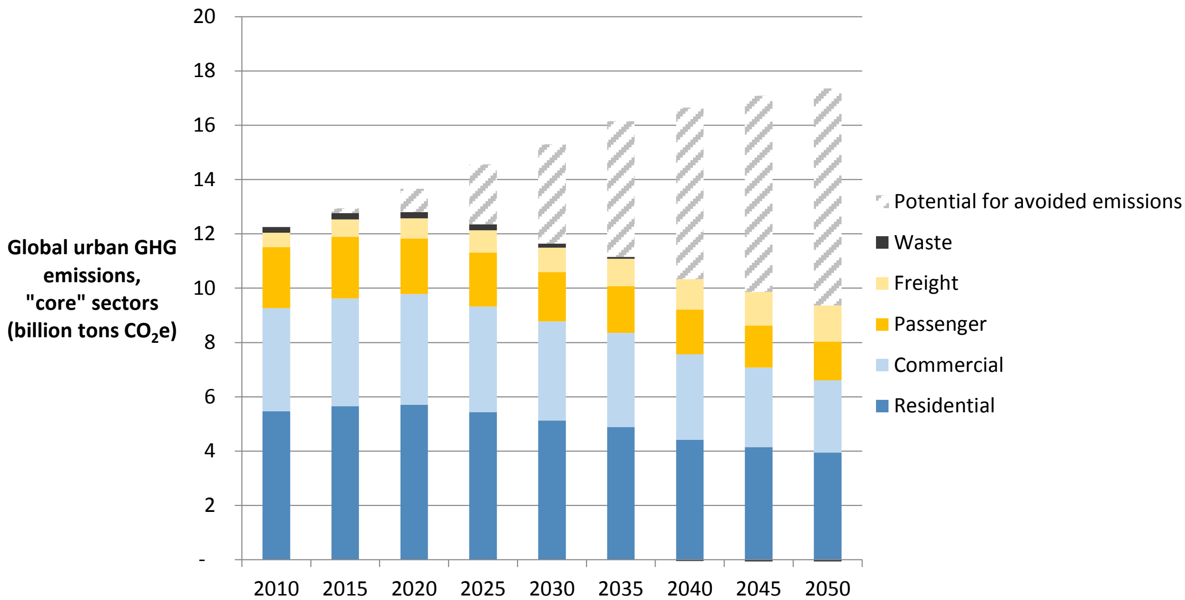
The aggregate GHG emission-reduction potential of urban action is under-explored, and under-appreciated. National emissions pledges and action plans have tended to focus primarily on measures that can be implemented across sectors of the economy, especially those related to electricity production and industry processes; they have seldom explicitly considered or reflected urban actions (Roelfsema et al. 2013; Fekete et al. 2013; IEA 2013). As a result, new city actions can largely be considered *additional* to committed national actions, whether in existing pledges or those under consideration, and could help deepen the ambition of both individual country as well as global climate targets.

3. Results

In aggregate, we find that urban action could reduce a set of "core" GHG emissions – those associated with urban buildings, transport, and waste disposal – by about one-quarter (24%) relative to a reference case in 2030 and by nearly half (47%) in 2050. This represents a reduction in global emissions of 3.7 Gt CO_2e in 2030 and 8.0 Gt CO_2e in 2050 (Figure 1), respectively. The urban action scenario achieves these reductions through a number of actions, as described below.

[2] At the time of our analysis, World Urbanization Prospects 2014 had not yet been released; global urban population forecasts in this new version differ by only about 1% compared to the 2011 version.

Figure 1. GHG emissions and emissions avoided in the urban action *scenario*



Urban building energy use can be cut dramatically through building retrofits and stringent codes for new building and appliance energy consumption. In the next few decades, urban housing will be constructed at unprecedented rates. This is especially true in areas that are both rapidly urbanizing and experiencing large increases in standards of living, such as China. However, considerable new urban housing is also likely to be developed in areas that aren't growing as fast, such as the US. In the reference case, roughly 40% of urban housing to be occupied in 2030 is not yet built as of today.[3] Constructing these buildings to be highly energy efficient now can dramatically reduce both energy costs to residents (even after considering any added cost of the more energy-efficient design) and GHG emissions, as well as decrease the cost of future emission-reductions (Ürge-Vorsatz et al. 2012).

Buildings already in existence today, however, comprise the balance – roughly 60% – of urban housing to be occupied in 2030, and, given their older construction, an even greater share of energy use. Therefore, building retrofits are a central strategy in reducing urban building energy use in the urban action scenario.

Over half of current global household energy use is for space and water heating (IEA 2014). In the reference scenario, the energy intensity of heating declines steadily, between 1% and 2% per year, due to gradual improvements in heating equipment and building insulation (IEA 2014).

For new buildings, the urban action scenario pursues building designs and technologies that reduce heating energy consumption dramatically further – down to "passive house" levels for new buildings in most areas (15 kwh of heating energy per m^2 of floor space) (Ürge-Vorsatz et al. 2012). This is

[3] Calculated based on assuming that new structures are constructed to match net urban population growth (UN 2011) and that existing structures are retired at the rate of 1.4% per year (Ürge-Vorsatz et al. 2012).

approximately one-tenth of the current average value in Europe, one-fifth of that in the US, and one-quarter of that in China.

The *urban action* scenario also begins an aggressive building retrofit program in 2015 that results in retrofit of all existing buildings by 2040 with reductions in energy intensity of 30% to 40% compared to the reference scenario.[4] The *urban action* scenario sees new and retrofit buildings also incorporate increasing adoption of solar hot water heating, plus heat pumps as the primary heat source (where heat is needed), lowering energy consumption for heating to just a small fraction of current demands. In some areas, these reductions could also be achieved by provision of district heat, if powered by low-GHG biomass or waste heat.[5] Lastly, both the reference and *urban action* scenarios include a gradual transition from traditional biomass to modern fuels for cooking and heating, especially in cities in Sub-Saharan Africa and developing Asia (IEA 2010). Should this transition free up low-GHG biomass for other, more efficient uses in industry and power, other GHG benefits may result that are not considered here.

Together, improvements in space and water heating reduce urban housing emissions by 1.1 Gt CO_2e annually in 2030 and 2 Gt CO_2e annually in 2050. Rapid introduction of low-energy appliances (including home electronics and kitchen equipment, among others)[6] and lighting (especially LED lighting) reduce emissions even further, as does the increasing installation of solar PV technologies on building rooftops and facades (Figure 4).[7]

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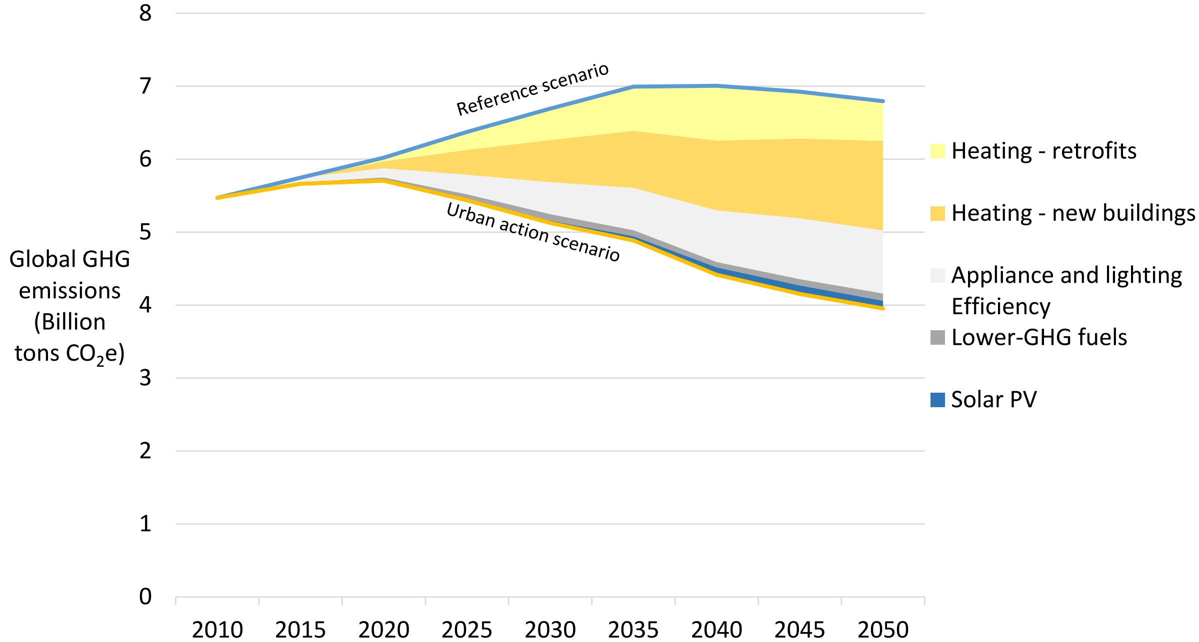
[4] Based on a Global Buildings Performance Network study (Ürge-Vorsatz et al. 2012), the urban action scenario begins by assuming retrofits of 1.3% of buildings annually in 2015, increasing to 3% of buildings in 2020, until all buildings have been retrofitted.

[5] The urban action scenario is constructed assuming heat pumps are applied in mid-latitude areas with significant heat demands. District heat could be an option where the infrastructure already exists and where low-GHG fuels are available (e.g., some parts of Europe). However, where district infrastructure has not yet been built, it may not be cost-effective to develop the heating networks to supply buildings with very low (e.g., passive house level) heating demands. Furthermore, where low-GHG fuel supplies – such as low-GHG biomass – are limited but sources of renewable electricity are relatively plentiful (e.g., China), district heat may not be as cost-effective as heat pumps for deep emission reductions, except perhaps in the densest cities (Chen et al. 2013; Persson and Werner 2011).

[6] In our analysis, abatement due to improvements in cooling demands and efficiency are included under "appliances." The fraction of urban energy use required for cooling required more research.

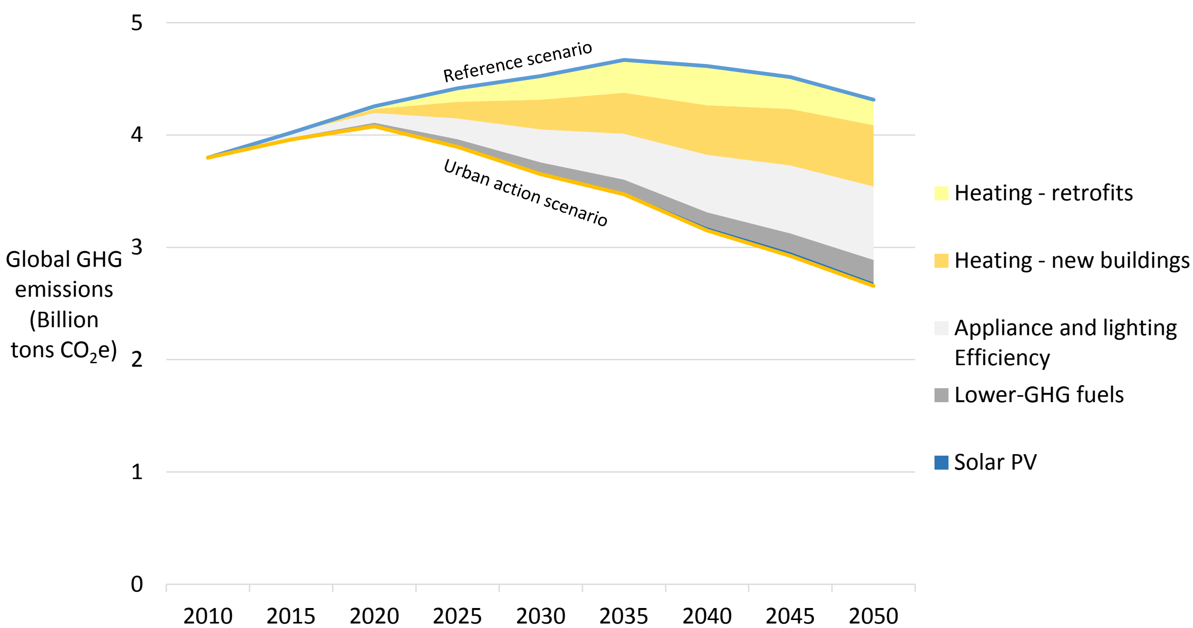
[7] In the urban action scenario, new solar PV (solar not in the reference scenario) provides up to 4% of building electricity demand (both residential and commercial) in 2030 and 10% in 2050 (this is over and above a similar amount assumed in the reference scenario). When not provided by PV, urban areas are assumed to source electricity from regional electricity grids.

Figure 2. Urban housing emissions in the reference and urban action scenarios



Similar improvements in building energy are possible in urban commercial buildings. Since commercial buildings require greater use of appliances and lighting than do most residences, the abatement potential from these technologies is proportionally greater (Figure 5).

Figure 3. Urban commercial building emissions in the reference and urban action scenarios

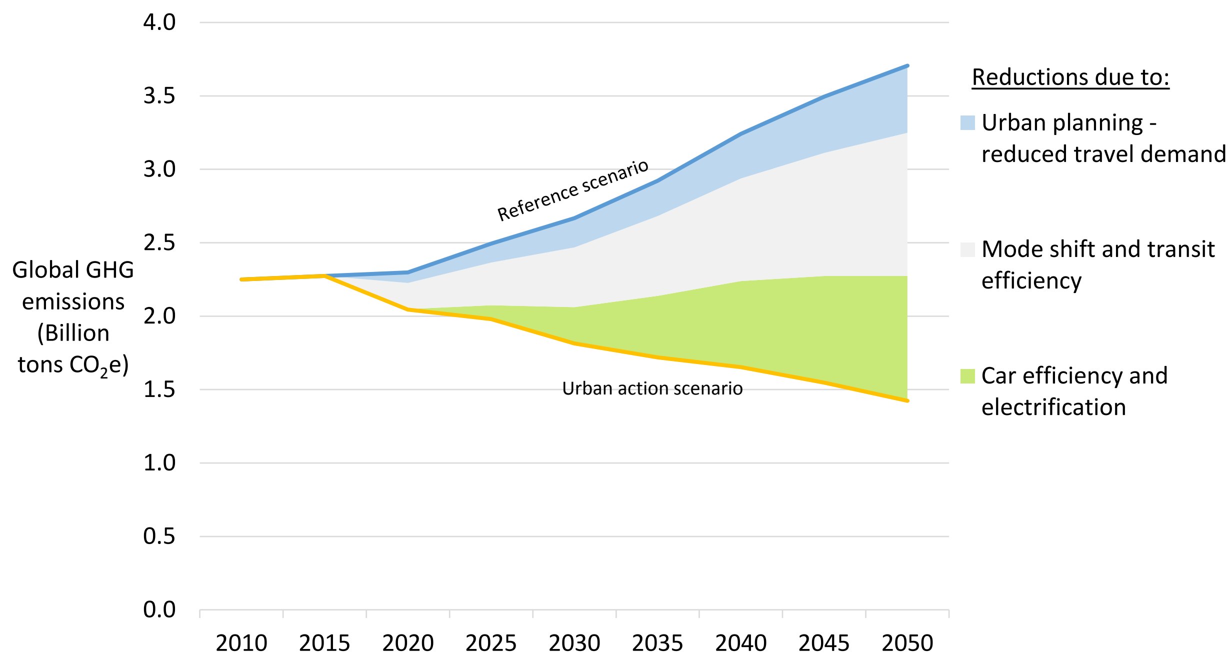


Compact, transit-oriented urban forms decrease GHG emissions and enhance passenger mobility and access. Personal travel demands are changing rapidly in many parts of the world, especially in rapidly growing and urbanizing China and India, where passenger travel is expected to double by 2030 (IEA 2014). How cities are built will dramatically determine whether future travel patterns are sprawling and car-based or compact with a significant share of public transport and non-motorized travel. In the *urban action* scenario, city governments, especially those in developing countries, increasingly plan compact, pedestrian and transit-oriented communities. These actions considerably slow the trend of increasing personal vehicle use in these countries, yielding equal (or greater) mobility by providing proximity to local services and greater availability and convenience of public transport, cycling (including e-bikes), and walking. Cities in OECD countries also pursue more compact forms – especially through in-fill development, to deepen an existing trend of declining personal vehicle use. Cities in North America make increasing use of light rail and subways for urban transportation, and cities in Europe and Japan that already have advanced train networks supplement these with expanded bus services (Replogle and Fulton 2014). Because of these investments, the *urban action scenario* sees the global mode share of private vehicles decline from 64% today to 53% in 2050 (compared to 72% in 2050 in the reference scenario). Achieving this shift would require aggressive and rapid construction of public transport at considerable cost, but could still result in net cost savings given the considerable resulting reduced fuel consumption over time (Replogle and Fulton 2014).

Furthermore, the urban action scenario sees cities increasingly using their vehicle-licensing authorities to support – or even extend – planned national vehicle efficiency standards, especially for vehicle efficiency technologies that are particularly well-suited to the urban environment, such as hybrid and electric technologies for both personal vehicles and buses.

Together, the changes in urban form, transport habits, and vehicle technologies allow overall urban passenger transport emissions to peak and begin declining in all developing countries by 2050. GHG emissions from urban passenger transport have already peaked in most OECD countries, but could decline to roughly half of current levels by 2030. Combined, the reductions in personal urban transport GHG emissions amount to 32% from reference levels in 2030, and 62% in 2050.

Figure 4. Urban passenger transportation emissions in the reference and urban action *scenarios*

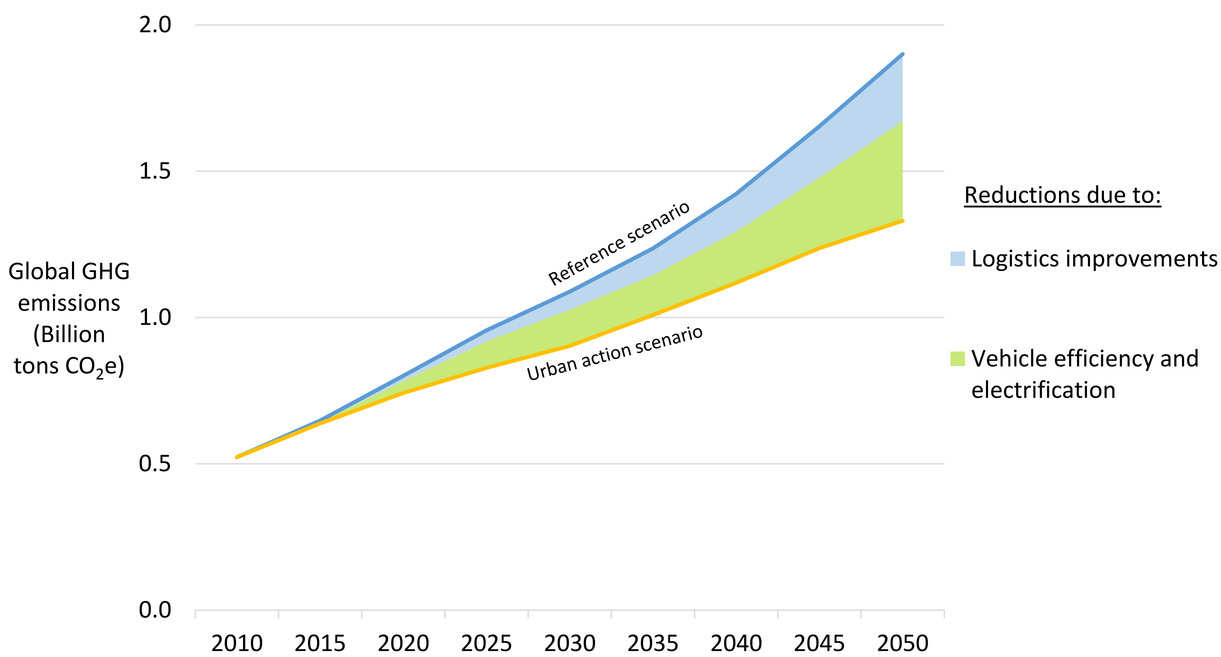


Improving urban freight logistics – and vehicles – can reduce "last leg" freight energy consumption. Increasing global wealth is enabling higher consumption and, in turn, demanding ever-greater shipping of products. This is particularly true in countries with fast-growing economies, but also in OECD countries. About one-quarter of an average product's travel (as measured in tonne-kilometers) occurs in the final transportation step – from producer to the final retailer or consumer (Nealer et al. 2011). This "last leg" may be influenced by urban policy on roadways and vehicles.

Shipping operations already have a strong incentive to reduce costs by reducing delivery times and associated energy use, but further potential improvements remain. In particular, because urban freight delivery can be complicated by congested urban roads and complicated routes, urban policies that help freight avoid these delays and simplify their routing – or allow for vehicles to burn less (or no) fuel when in stop-and-go-traffic – can reduce overall freight energy use.

The urban action scenario therefore sees city governments supporting improvements in freight logistics, such as consolidating freight in new shipping centers at urban peripheries, shifts in time of delivery, and technology-enabled, real-time improvements in routing. Together, these improvements enable a reduction of road-freight demands (reduced tonne-kilometers) of 5% compared to the reference scenario in 2030 (ICCT 2012) and 10% or more in 2050 (Cambridge Systematics 2009). In addition, through vehicle licensing policies, local governments could contribute to more-efficient freight vehicles, whether through hybrid engines with idle-off technology or electric motors that would be highly suitable to the urban environment and also help reduce particulate emissions. A reduction in urban passenger travel, as described above, also facilitates efficient freight delivery by allowing delivery trucks to avoid stop-and-go traffic. Together, these improvements in freight logistics and vehicle efficiency reduce urban road freight GHG emissions by about 20% compared to a 2030 reference case and 30% compared to a 2050 reference case. (These reductions could also have additional climate benefits to the extent that reduced diesel use decreases emissions of black carbon and ozone precursors.)

Figure 5. Urban road freight emissions in the reference and urban action *scenarios*



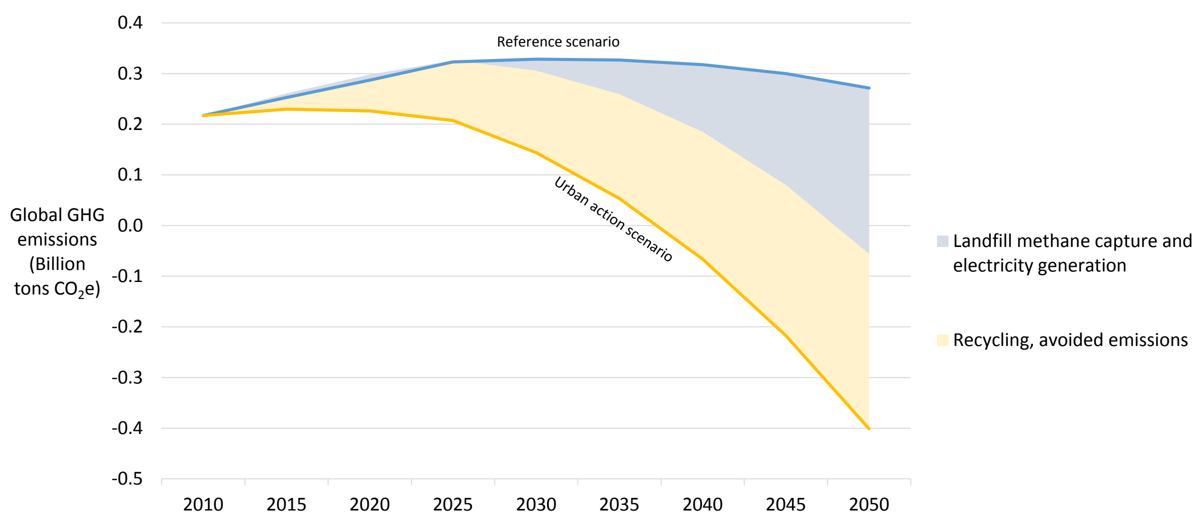
Expanded recycling and better landfill gas management can reduce GHG emissions associated with urban waste management

Increasing global consumption levels are creating increased demand for products and, in turn increased production of municipal waste as well as a growing waste management infrastructure. Waste products – especially those with organic content, such as wood, paper, and food – create the highly potent greenhouse gas methane (CH_4) when they decompose in anaerobic landfill conditions. However, these same landfill conditions limit decomposition, creating a long-term storage of carbon that would not otherwise occur. In most cases today, unless a landfill captures most of its methane, the GHG emissions outweigh the benefits of the stored carbon, leading landfills to be net sources of GHG emissions.

In our *urban acti*on scenario, cities influence GHG emissions associated with solid waste by collecting and managing refuse in ways that limit methane release and maximize the benefits of recycling. In developing cities, this starts with higher rates of centralized refuse collection to limit disposal in informal dumps. In all cities, methane releases can be limited by choosing landfill destinations that operate highly effective methane-capture systems and, where possible, use that methane to create energy that would otherwise often be generated from GHG-emitting fossil fuels. Similar GHG reductions can also be achieved via systems that convert waste directly to energy, whether through combustion or other processes. Higher recycling rates are possible in nearly all cities and can help avoid significant energy associated with making new materials, especially for energy-intensive materials such as steel and aluminum.

In total, the urban action scenario sees waste collection, recycling, and methane capture rates increase to very high levels in all cities, leading to an elimination of (net) landfill GHG emissions[8] and further reductions due to recycling and the resulting energy savings in industry (Figure 6).

Figure 6. Urban waste management net emissions in the reference and urban action scenarios



Other urban opportunities for emission reductions

While local policy influence is, arguably, highest in the buildings, transport, and waste sectors, these are not the only areas where local action can be taken to reduce GHG emissions. Some cities have influence over the energy and emissions-intensity of other transport activities not considered here, such as marine or airport emissions. Communities also have opportunities to reduce GHG emissions in the power, industry, and agricultural sectors. For example, cities can often encourage – or require in the case of municipal utilities – their electricity providers to move away from fossil fuels for power and expand investments in renewable energy. Through zoning and other mechanisms, cities can encourage industrial material and waste energy exchanges to lower the GHG-intensity of industrial production. Through services designed to increase sharing of, and therefore reduced need for, new products, cities can reduce emissions associated with the production of goods. Should cities demonstrate effective means of steering residents to healthier, low-GHG diets, they may contribute to emission-reductions in agriculture and forestry, through decreased demand for meat from livestock. Although these opportunities were not quantified as part of our *urban action* scenario, they remain important opportunities that deserve further research attention and policy development.

3. Discussion and conclusions

New efforts are needed to deepen the ambition of current national GHG-reduction pledges. This research indicates that, in aggregate, aggressive urban actions have the potential to reduce GHG emissions by about 3.7 Gt CO_2e in 2030, rising to approximately 8.0 Gt CO_2e in 2050 (Table 1).

[8] This is not to say that all methane emissions are eliminated, but that methane capture increases to an extent that they are balanced, on a CO_2-equivalent basis, by landfill carbon storage.

Table 1. Urban abatement by sector in the urban action scenari*o, 2030 and 2050*

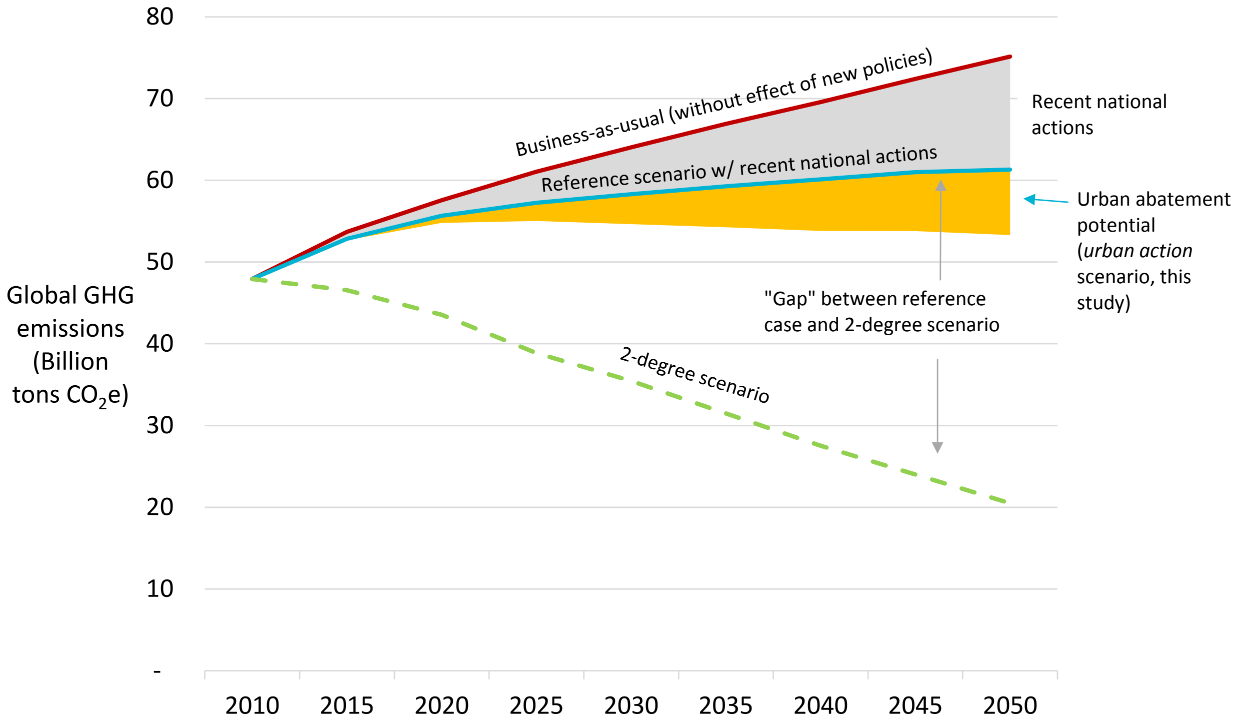
Sector	**Technology or practice**	Abatement, Gt CO_2e		Share of total Abatement, %	
		2030	2050	2030	2050
Buildings, residential	New building heating efficiency	0.6	1.2	16%	15%
	Heating retrofits	0.4	0.5	12%	7%
	Appliances and lighting	0.4	0.9	12%	11%
	Fuel switching / solar PV	0.1	0.2	3%	3%
Buildings, commercial	New building heating efficiency	0.3	0.5	7%	7%
	Heating retrofits	0.2	0.2	6%	3%
	Appliances and lighting	0.3	0.7	8%	8%
	Fuel switching / solar PV	0.1	0.2	3%	3%
	Subtotal, buildings	2.4	4.5		
Transport, passenger	Urban planning - reduced travel demand	0.2	0.5	5%	6%
	Mode shift and transit efficiency	0.4	1.0	11%	12%
	Car efficiency and electrification	0.2	0.9	7%	11%
Transport, freight	Logistics improvements	0.1	0.2	2%	3%
	Vehicle efficiency	0.1	0.3	3%	4%
Subtotal, transport		1.0	2.9		
Waste	Recycling	0.2	0.3	4%	4%
	Landfill methane	0.0	0.3	0%	4%
	Subtotal, waste	0.2	0.6		
Total		**3.7**	**8.0**		

Given the lack of consistent data on urban GHG emissions, as well as difficulties in defining "urban", these results should be interpreted with caution, and more research is clearly needed. At the same time, some insights emerge that are likely to be robust – namely, that, globally, significant GHG abatement opportunities available to urban policymakers (i.e., those which correspond to at least 10% of the abatement potential in 2030 in Table 1) are likely to be:

- deep building shell energy standards for new urban residential buildings (especially in fast-growing, developing cities in regions with higher heating demands); and
- building energy retrofits for urban residences (especially in already-highly-developed cities in regions with higher heating demands; and
- aggressive energy performance standards for urban building lighting and appliances, and
- mode shift and transit efficiency for personal urban mobility.

Realizing the full potential of these actions would necessarily require bold and swift action by the world's cities, and could be aided by new sources of finance and national policy support. At the same time, because few of the actions considered here are currently included in national pledges, realization of this abatement could help extend the ambition of current national pledges, or help nations deepen new commitments currently under consideration (Figure 7).

Figure 7. Urban action could help deepen the aggregate, global ambition of current national pledges[9]



The need to deepen the ambition of national emissions pledges from current pathways to one consistent with limiting warming to 2 degrees C has sometimes been called the emissions "gap". This study finds that aggressive urban action could close the gap (the difference between the blue and dotted green lines in Figure 7) by at least 10% in 2030, and by approximately 15% in later years, as continued construction of compact, efficient urban infrastructure yields dividends. Even greater reductions could be possible were cities able to exert greater control over their electricity supplies or demonstrate low-carbon lifestyles for other aspect of resident carbon footprints, such as product purchasing and food consumption.

[9] Chart sources (other than this study): BAU and "reference scenario" differ only in their assessment of energy-related CO2 emissions: BAU uses IEA's 6DS scenario, reference uses 4DS; (IEA 2014); for other gases, both scenarios use the average of BAU scenarios in the IPCC AR5 scenario database, 2-degree pathway from Rogelj et al (Rogelj et al. 2011).

Appendix: Methodology and detailed results

Urban areas considered

This study includes all urban agglomerations considered by the UN's World Urbanization Prospects: over 600 individual urban agglomerations (modeled individually) with 2010 population of at least 750,000, as well as about 3,000 other areas (modeled in regional aggregations) with 2010 population of less than 750,000. Figure 8 describes the distribution of the future urban population by (current) size of each region. Note that most of the urban population resides in areas with less than 750,000 people.[10]

Figure 8. World urban population forecast, by size of urban population in 2010 (UN 2011)

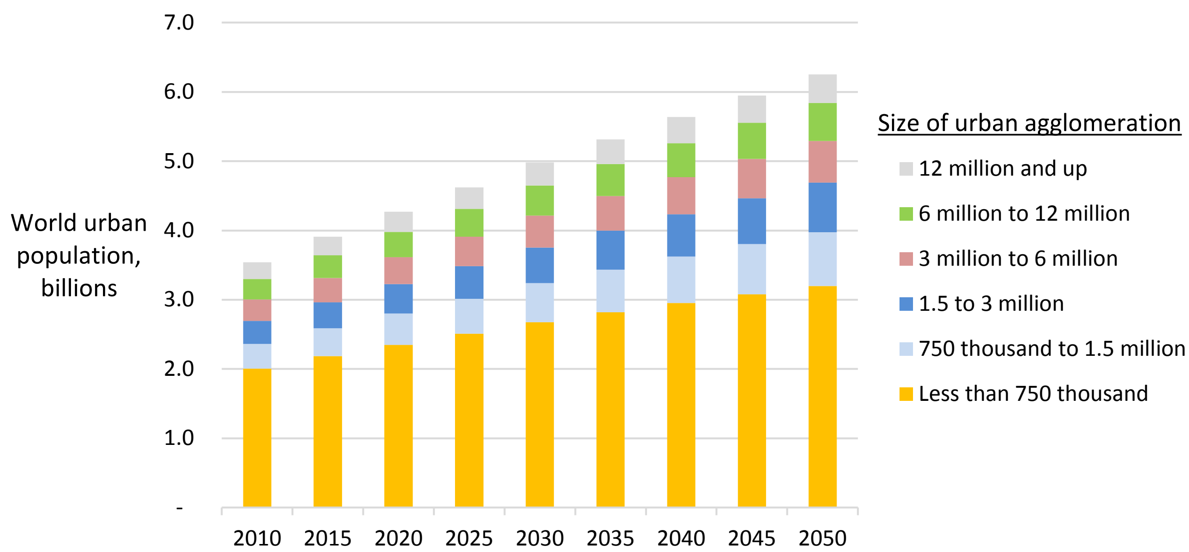
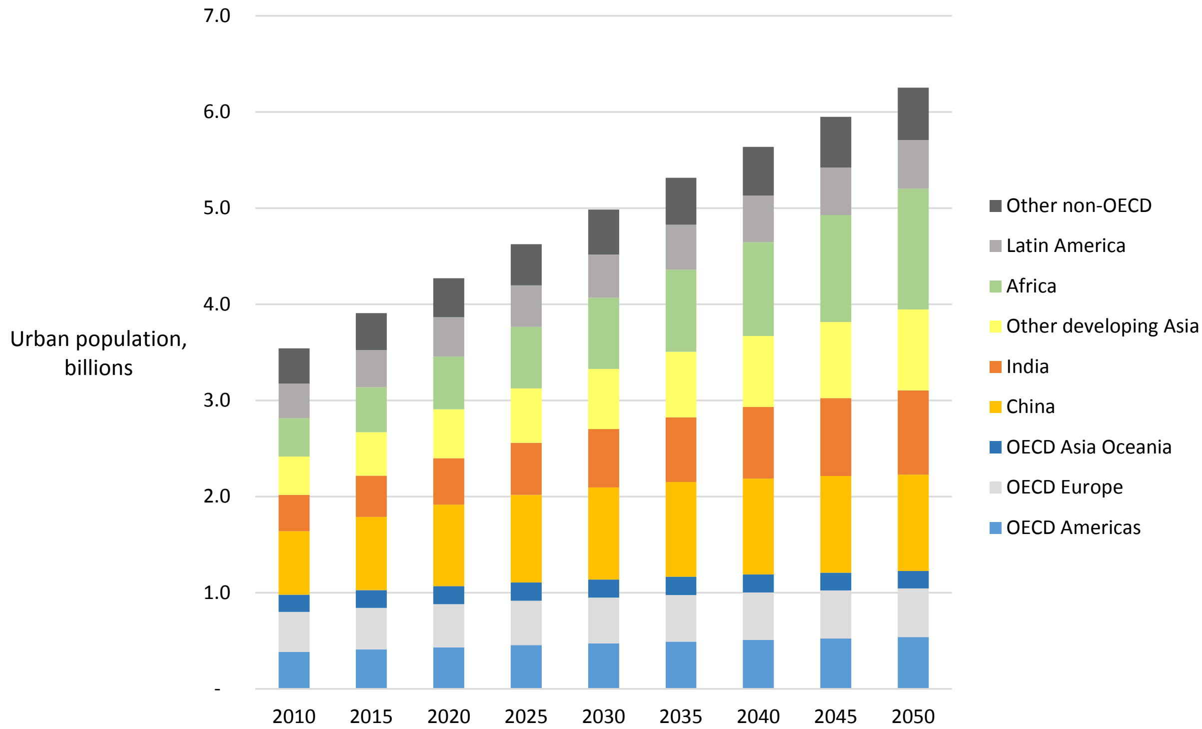


Figure 9 describes the distribution of future urban population by region. Note that nearly all of the net growth in urban population is expected to occur in cities in developing countries.

[10] The future growth of urban areas with populations less than 750,000 may be underestimated in this chart and in UN analysis because the UN does not estimate what areas that are not "urban" today may become "urban" in the future.

Figure 9. World urban population forecast, by region (UN 2011)



Scenario methodology

Broadly speaking, we apply a "bottom up" scenario analysis framework, an approach commonly used in GHG abatement literature.(IPCC Working Group III 2014; IEA 2013; GEA 2012). It first involves developing a reference case scenario of the future economy, energy patterns, and GHG emissions of cities. Many technologies in use in the urban area will improve over time, due to market forces and national policy. For example, personal vehicles will continue to become more efficient, due both to market-driven technology innovation as well as due to mandated efficiency standards, such as those in use in China, the EU, and the US These trends are built into the reference scenario, based predominantly on the IEA's *Energy Technology Perspectives* 4DS scenario (IEA 2014), which itself is consistent with the IEA's *New Policies* scenario of *World Energy Outlook* (IEA 2013). For urban areas in each region, the reference scenario is constructed by multiplying urban population by activity drivers (e.g., passenger travel or residential floorspace per person) by energy-intensity (e.g. energy per unit of passenger travel or floorspace) by GHG-intensity of energy. From this reference scenario, the *urban action* scenario departs by applying technologies and practices in urban areas to reduce GHG emissions, such as building energy retrofits, transportation and urban planning, or recycling. (The abatement options considered are discussed further below). Abatement potential is then calculated in each year as the difference in emissions between reference scenario and the *urban action* scenario. (For detailed results and global average figures for key drivers, such as building energy intensity or passenger vehicle travel, see Table 4, below.)

Emissions sources and abatement activities

This analysis focuses on emissions sources and activities where abatement potential, local influence, and data availability are greater. More specifically, the following criteria were used to guide the selection of emissions sources and activities:

- Average urban-scale GHG abatement potential, to help focus the analysis on the emissions sources where the application of mitigation technologies and practices can make a significant (i.e., >1%, on average) reduction in an average urban resident's carbon footprint.
- Local influence by urban-scale policymakers, as demonstrated by prior research commissioned by C40;(Erickson et al. 2013)
- Data availability, or the ability to reasonably approximate urban-scale GHG emissions and underlying drivers (e.g., transport activity, building energy use).

Table 2 presents an assessment of emissions sectors according to these criteria, where dark circles indicate "high" and empty circles indicate "low". Excluding sectors with a "low" rating in any of the three criteria suggest four sectors as priority for initial focus, as in this study: energy supply,[11] buildings (both residential and commercial), transport (including both passenger and freight), and waste management.

Table 2. Assessment of urban GHG emissions sectors
(Dark circles = High; empty circles =low)[12]

Sector	Average urban-scale GHG abatement potential, 2020	Urban policy influence	Data availability	Assessment
Energy Supply	●	◯	◯	Initial focus
Buildings	◯	●	◯	Initial focus
Transport	◯	●	◯	Initial focus
Industry (production) and goods (consumption)	◯	◯	○	
Agriculture and Food	●	○	◯	
Urban forestry	○	●	○	
Waste Management	◯	◯	◯	Initial focus

Emissions accounting and boundaries

Some activities that occur inside city or urban boundaries result in emissions outside the urban boundary (or vice versa). For example, most cities rely on electricity that is generated outside the urban boundary, and that when produced with fossil fuels, releases GHG emissions. Following urban GHG-

[11] The focus on energy supply will be on energy supply to buildings and transport. Because industry is not suggested as an initial focus here, energy supply to industry will also not be included.

[12] Data sources used here: average urban GHG abatement potential and urban policy influence from a C40/SEI analysis(Erickson et al. 2013), data availability by SEI for this memo. Note that GHG abatement potential in the long term (2050) would receive a "high" rating for buildings and transport.

accounting protocols, this analysis includes emissions associated with producing electricity consumed within urban areas, regardless of where the electricity is produced. Likewise, this analysis excludes emissions associated with electricity produced in urban areas if it is consumed elsewhere. Similarly, the analysis includes emissions associated with waste generation (e.g., landfill disposal) of waste generated in urban areas, even if that disposal occurs outside the urban boundary.

Besides electricity and waste, other choices within the urban boundary may also affect emissions outside the boundary. For example, the choice of heating fuel, such as coal versus natural gas or gasoline versus biofuel, influence not only the emissions associated with combustion of those fuels, but also the emissions associated with the fuels' production. In some cases, the difference in these "upstream" or "life cycle" emissions can be significant enough to substantially affect the overall emissions implications of choosing one fuel or another. The methane leakage associated with natural gas production, distribution, and sale to end users, for example, can outweigh the benefits of lower-carbon fuel combustion for some applications, including for vehicles (Alvarez et al. 2012). Similarly, emissions associated with biofuel production can in many cases dramatically lower the net GHG benefits relative to gasoline or diesel (CARB 2009).

Because of these differences, and to more fully account for the GHG emissions implications of measures to reduce or shift fuel consumption, this study accounts for emissions on a life-cycle basis, including the emissions associated with producing each fuel, also based on analysis by the International Energy Agency (IEA 2014).

Key data sources

For each sector, Table 3 describes the key data sources used to construct the reference case, as well as the abatement options considered in the *urban action* scenario.

Table 3. Assumptions and data sources for estimating reference case emissions and abatement potentials (Adapted from Energy Technology Perspectives (IEA 2014; IEA 2012) unless otherwise noted)

Sector	Reference case activity levels	Reference case energy intensities	Reference case GHG-intensities of energy	Abatement technologies and practices considered
Buildings	Residential urban floor space intensity (m^2 per person) assumed same as national averages, grows slowly (<0.5% per year) in OECD countries, faster (>1% per year) in developing countries Commercial floor space assumed to be predominantly in urban areas (90% or more)[13]; intensity (m^2 per person) grows more quickly in cities in developing countries than those in developed countries.	Residential and commercial urban energy intensities (GJ and kwh per m^2) follow national averages in OECD and some developing countries; in majority of developing countries, adjusted from national averages using rural / urban splits of electricity access and traditional biomass use.[14] Heating intensities are adjusted from population-weighted national averages based on city-specific heating demand.[15] Worldwide urban energy intensity declines <1% per year for residential buildings, remains nearly constant in commercial buildings as efficiency gains balanced by increased energy demand, mainly in developing world.	Urban heating fuel and electricity GHG-intensities ($kgCO_2e$ per GJ or MWh) match national averages in OECD and some developing countries; in the majority of developing countries adjusted from national averages using rural / urban splits of fuel types based on electricity access and traditional biomass use.[14] Urban fuel GHG intensities decline gradually with shift away from coal and oil; electricity intensities decline more rapidly (1-3% annually) based on recent national energy policies.[16]	New building standards at passive house levels;[17] deep building shell retrofits at 1.4% to 3% of building stock per year;[18] and including heat pumps in mid-latitude countries;[19] aggressive implementation of efficient lighting and appliances;[20] increasing adoption of rooftop and building-integrated solar PV.[21]

[13] Based on the assessment of Global Buildings Performance Network (Ürge-Vorsatz et al. 2012).

[14] Based on the 2010 World Energy Outlook (IEA 2010) data for Africa, China, India, Other Asia, and Latin America.

[15] City heating demands were assumed to scale linearly with heating degree days (Kennedy et al. 2009); heating-degree day (HDD) data for cities taken from degreedays.net (data retrieved May 2014, covering previous 3 years of weather station data); HDD data for nations from World Resources Institute's CAIT tool (Baumert and Selman 2003).

[16] Grid carbon intensity is based on the new policies scenario of the 2013 version of the World Energy Outlook (IEA 2013) through 2035, with subsequent declines through 2050 based on the percentage change by region in the 2012 Energy Technology Perspective (IEA 2012).

[17] Passive house levels for new builds are assumed to no less than 30 kWh/m^2 annual heating requirement for new buildings from 2020 to 2030, then 15 kWh/m^2 for new builds through 2050. In some regions, where heating demands are greater (i.e. Russia), passive house construction results in higher heating demands (Ürge-Vorsatz et al. 2012).

[18] The assessment of building energy retrofit rates and energy intensities (both for retrofits and new buildings) is guided by GBPN's analysis (Ürge-Vorsatz et al. 2012).

[19] Heat pumps are installed in all new buildings and retrofits after 2020 in regions with average heating degree days between 2,000 and 5,000, based roughly on IEA (IEA 2014): China, Japan, OECD Europe, and United States. In regions with heating degree days near but outside of this range (Eastern Europe and Eurasia, Other OECD Americas, Russia), heat pumps are implemented in half of post-2020 new buildings and retrofits.

[20] Assumptions for appliances and lighting are based on the IEA's 2DS scenario (IEA 2014).

[21] Estimate potentials for solar PV expansion based on assuming that half of the solar PV in IEA's 2DS scenario (IEA 2014) is distributed PV, and that the distributed PV is built in urban areas proportional to the share of urban population in each country analyzed. For any given city, we limit generation capacity at the maximum (0.5 W/m^2) level identified by an IIASA assessment (Grubler and Fisk 2012).

Sector	Reference case activity levels	Reference case energy intensities	Reference case GHG-intensities of energy	Abatement technologies and practices considered
Transport	Urban passenger travel intensity (pkm per person) continues a slow decline in cities in OECD countries, but grows steadily (~1.5% or more annually through 2030, slowing through 2050) in developing countries; mode share holds relatively constant in OECD countries, but shifts strongly to private vehicles in developing countries. Urban freight intensity (tkm per person) grows steadily in both OECD countries (1-2% per year) and non-OECD countries (2-6% per year)	Urban passenger vehicle energy intensities (MJ/pkm) for private, bus, and train modes assumed same as national averages; generally decline 0.5-1% annually through 2050 for all modes, although private car energy intensity increases 0.5-1.5% annually in developing Asia due to larger cars, less carpooling. Freight energy intensity (MJ/tkm) assumed same as national average road freight intensities. Generally declines 0.5-1% annually in OECD countries and many developing countries, but does not decline in Russia, China, or India.	Urban fuels are assumed to be predominantly gasoline and diesel (or GHG-equivalent biofuels) for the duration of the period analyzed. However, gradual introduction of private electric vehicles leads to small changes in GHG-intensity by 2050 (from a 3% decline to 4% increase in GHG intensity, depending on electric grid).	Land use planning for compact urban form reduces passenger travel activity (pkm / capita) up to 7% in OECD countries and 25% in developing countries;[22] rapid expansion of public transport leads to 20% lower pkm mode share of LDVs;[23] more-efficient (including more widespread deployment of electric vehicles) result in over 45% improvement in private vehicle efficiency globally[24]; increased operational efficiency of the road network and transport system[25]

[22]Reduced motorized transport activities are based on allocating all reduction in road passenger transport demand in *Energy Technology Perspectives* (IEA 2014) to urban areas. These reductions are generally consistent with the opportunity found in studies of individual cities (Hickman et al. 2011). In addition, fright transport logistics improvements lead to a 5% reduction in tkms / capita by 2030 and 12% by 2035 (ICCT 2012).

[23] Assumptions about expanded mode share of public transport are adapted from an ITDP and UC Davis study (Replogle and Fulton 2014).

[24] For passenger transport, the energy intensity impact of electrification is based on the 2DS scenario variant *Electrifying Transport* (IEA 2014) for cars (light road), buses (heavy road), and rail beyond the share of energy from grid electricity reported in ETP 2012 (IEA 2012). For freight transport, one quarter of energy demand is assumed to be electrified, based on the *Electrifying Transport* variant (IEA 2014).

[25] Based on vehicle efficiency improvements resulting from ramp metering, active traffic management, integrated corridor management, incident management, and signal control management as in *Moving Cooler* for the U.S. (Cambridge Systematics 2009).

Sector	Reference case activity levels	Reference case energy intensities	Reference case GHG-intensities of energy	Abatement technologies and practices considered
Waste management	Waste generation (tonnes waste per capita) (Hoornweg and Bhada-Tata 2012) holds stable in OECD regions through 2025, while growing annually 1.5% or more in most developing regions.[26] Post-2025, waste generation in each region converges to a fixed global relationship with GDP in 2050 (based on projected waste per capita / GDP in 2025). Waste fractions by type of waste (IPCC 2006) are assumed to remain constant.[27]	Energy and GHG-emissions avoidance based on fraction of waste collected, assumed constant (IPCC 2006), and managed via recycling (including composting) or landfilling. Recycling (and composting) rates assumed to converge everywhere to current best practice (Hoornweg and Bhada-Tata 2012) by 2050.	For landfilling, the share of methane captured, a combination of increasing share of methane capture facilities and increased capture efficiency at these facilities, grows faster in developing countries (3.1% per year) than in OECD countries (1.0% per year).[28, 29] Stored carbon in landfills increases with higher waste generation rates but decreases with paper recycling and food composting.[30] Other determinants of stored carbon are assumed constant. These include: collection rates, degradable organic content (DOC) and fraction of DOC that decomposes (IPCC 2006). For recycling, emissions avoided represent a share of the emissions intensities (tCO_2e/t product; IEA 2014) of production for paper, steel, aluminum, and plastics.[31] As new product efficiencies improve over time, avoided emissions from new production correspondingly decrease.[32]	Increased fraction of waste collected, converges to 2010 best practice (90%; IPCC 2006) in all regions by 2050; Increased recycling rate, to 80% of recyclables from collected waste in all regions by 2050; Increased fraction of methane captured: developing countries 5.5% annual growth, OECD countries 2.5% annual growth;[33] Greater electricity generation from landfill gas in all regions: 2% annual growth in methane capture capable facilities that also generate grid electricity.[34]

[26] For waste emissions, regional designations match with the IPCC Waste model (19 total regions: 5 in Africa, 4 each in Asia and Europe, 4 in the Americas including Caribbean, and 2 in Oceania).

[27] Waste fractions are taken from the IPCC Waste Model (accessed online at http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html).

[28] This difference between OECD and developing countries is primarily from the assumed faster growth in facilities with methane capture capability (2.8% vs 0.7%). Capture rate at these facilities improves 0.3% per year over current average best practice of 50% (IPCC 2014) in all regions.

[29] It is assumed that one-quarter of the methane capture facilities are also equipped to generate electricity for the grid in 2010. This is assumed to remain constant in the reference case in all regions through 2050.

[30] Increased paper recycling and food composting rates, modest in the reference case, result in both avoided landfill emissions and foregone carbon sequestration, with the avoided landfill emissions greater than foregone carbon sequestration.

[31] The percent of production emissions avoided by incorporating recycled material varies with product. It is assumed to range from 50% for paper products and plastics, to 80% for steel and aluminum.

[32] Based on (IEA 2014) improved GHG intensities of production, range from marginal for aluminum production to 1% for paper products and plastics.

[33] Increased methane capture is achieved both through increasing the share of facilities equipped with methane capture capability (up to 80% in OECD and 50% in non-OECD regions by 2050, relative to reference scenario of 30% and 65%, respectively) and increasing the efficiency of methane capture at these facilities (up to 84%, a 1.3% annual growth rate, by 2050 in all regions, relative to reference scenario of 56%, a 0.3% annual growth rate).

[34] Compared to 0.0% growth in reference case. In all regions, 55% of methane capture facilities also generate grid electricity. Based on the EPA WARM model (US EPA 2014), each tCO_2e of methane combusted generates 175 kWh of electricity (assuming 85% conversion efficiency).

Detailed Results

Table 4. Detailed global results for the reference and urban action scenarios
(Note: all energy, GHG, and activity intensities reported here are global average results, country-specific inputs may vary)

	Reference scenario									Urban action scenario								
URBAN TOTALS	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Population (million)	3,541	3,909	4,271	4,624	4,984	5,314	5,636	5,950	6,252	3,541	3,909	4,271	4,624	4,984	5,314	5,636	5,950	6,252
Annual GHG emissions (GtCO2e)	12.3	12.9	13.7	14.6	15.3	16.1	16.6	16.9	17.0	12.3	12.8	12.8	12.3	11.6	11.2	10.3	9.7	9.0
Cumulative GHG emissions (GtCO2e) from 2015	--	--	67	137	212	290	372	456	541	--	--	64	127	187	244	297	347	394
Annual energy demand (EJ)	114	122	131	141	151	161	173	184	195	114	120	121	117	111	107	105	107	111
RESIDENTIAL BUILDINGS																		
Emissions (GtCO2e)	5.5	5.7	6.0	6.4	6.7	7.0	7.0	6.9	6.8	5.5	5.7	5.7	5.4	5.1	4.9	4.4	4.2	4.0
Energy (EJ)	51	54	58	61	65	68	71	74	77	51	54	55	51	48	45	43	44	46
Energy per capita (GJ / resident)	15	14	13	13	13	13	13	12	12	15	14	13	11	10	8	8	7	7
Floor area (billion square meters)	102	116	133	147	161	175	188	201	213	102	116	133	147	161	175	188	201	213
Energy per floor area (GJ / m^2)	0.50	0.47	0.43	0.42	0.40	0.39	0.38	0.37	0.36	0.50	0.46	0.41	0.35	0.30	0.26	0.23	0.22	0.22
COMMERCIAL BUILDINGS																		
Emissions (GtCO2e)	3.8	4.0	4.3	4.4	4.5	4.7	4.6	4.5	4.3	3.8	4.0	4.1	3.9	3.7	3.5	3.1	2.9	2.7
Energy (EJ)	30	33	37	40	42	45	48	51	54	30	32	35	34	33	32	32	33	35
Floor area (billion square meters)	35	38	42	45	49	52	55	59	63	35	38	42	45	49	52	55	59	63
Energy per floor area (GJ / m^2)	0.87	0.87	0.88	0.87	0.87	0.87	0.87	0.87	0.86	0.85	0.84	0.83	0.75	0.68	0.62	0.58	0.57	0.55
PASSENGER TRANSPORT																		
Emissions (GtCO2e)	2.2	2.3	2.3	2.5	2.7	2.9	3.2	3.5	3.7	2.2	2.3	2.0	2.0	1.8	1.7	1.7	1.5	1.4
Energy (EJ)	26	26	26	29	30	33	37	40	42	26	26	23	22	20	18	18	17	15
Motorized travel (pkm, trillion)	20	22	25	29	33	36	40	43	46	20	22	24	28	30	33	36	38	40
Motorized travel per resident (pkm / resident)	5,700	5,720	5,810	6,380	6,600	6,850	7,120	7,250	7,320	5,700	5,720	5,600	6,030	6,120	6,290	6,450	6,440	6,400
LDV Emissions (GtCO2e)	1.8	1.8	1.8	1.9	2.0	2.3	2.6	2.8	3.0	1.8	1.8	1.6	1.5	1.4	1.3	1.2	1.2	1.1
LDV Energy (EJ)	21	21	21	22	23	26	29	32	35	21	21	18	17	15	14	13	13	12
LDV passenger kilometers (pkm, trillion)	13	14	16	19	22	24	27	30	33	13	14	14	16	17	18	20	20	21
LDV pkm / resident	3,650	3,650	3,700	4,100	4,340	4,560	4,850	5,050	5,240	3,650	3,650	3,360	3,510	3,460	3,470	3,490	3,430	3,370
LDV energy intensity (MJ / pkm)	1.65	1.48	1.31	1.15	1.09	1.07	1.07	1.06	1.06	1.65	1.48	1.28	1.04	0.87	0.74	0.67	0.62	0.57
Mode Share of pkm - LDVs	64%	64%	64%	64%	66%	67%	68%	70%	72%	64%	64%	60%	58%	57%	55%	54%	53%	53%
FREIGHT TRANSPORT ("LAST LEG" ONLY)																		
Emissions (GtCO2e)	0.5	0.6	0.8	1.0	1.1	1.2	1.4	1.7	1.9	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
Energy (EJ)	6.4	8.0	9.9	11.9	13.5	15.2	17.1	19.3	21.7	6.4	7.8	9.0	9.9	10.6	11.6	12.5	13.6	14.5
Freight tonne-kilometers (tkm, trillion)	2.0	2.6	3.4	4.2	5.1	6.0	6.9	7.9	8.9	2.0	2.6	3.3	4.1	4.8	5.5	6.3	7.1	7.8
Freight per resident (tkm / resident)	570	670	790	910	1,020	1,120	1,220	1,320	1,420	570	670	780	880	960	1,040	1,120	1,190	1,250
Energy Intensity (MJ / tkm)	3.2	3.0	2.9	2.8	2.7	2.5	2.5	2.5	2.4	3.2	3.0	2.7	2.4	2.2	2.1	2.0	1.9	1.8

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