THE **NEW** CLIMATE **ECONOMY**

The Global Commission on the Economy and Climate

Working Paper

Accelerating Low-Carbon Development in the World's Cities

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Overview

Cities are engines of economic growth and social change. About 85% of global GDP in 2015 was generated in cities. By 2050, two-thirds of the global population will live in urban areas. Compact, connected and efficient cities can generate stronger growth and job creation, alleviate poverty and reduce investment costs, as well as improve quality of life through lower air pollution and traffic congestion. Better, more resilient models of urban development are particularly critical for rapidly urbanizing cities in the developing world.

International city networks, such as the C40 Cities Climate Leadership Group, Local Governments for Sustainability (ICLEI) and United Cities and Local Governments (UCLG), are scaling up the sharing of best practices and developing initiatives to facilitate new flows of finance, enabling more ambitious action on climate change. Altogether, low-carbon urban actions available today could generate a stream of savings in the period to 2050 with a current value of US$16.6 trillion.

Recommendation

The Global Commission on the Economy and Climate recommends that cities commit to developing and implementing low-carbon urban development strategies by 2020, using where possible the framework of the Compact of Mayors, prioritising policies and investments in public, non-motorised and low-emission transport, building efficiency, renewable energy and efficient waste management.

Donor agencies, city networks and organisations, multilateral and regional development banks and others should develop an integrated package of at least US$1 billion for technical assistance, capacity-building and finance to support commitments by the world's largest 500 cities. The package could directly mobilise at least US$5–10 billion in private investment through project preparation support, and leverage significant further large-scale capital for a low-carbon urban transition. The package should build on existing leadership and efforts by cities using their own resources, and prioritise filling critical resource gaps in smaller cities and cities in developing countries.

The actions suggested could reduce annual greenhouse gas (GHG) emissions by 3.7 Gt CO_2e by 2030.

About this working paper

This New Climate Economy Working Paper was written as a supporting document for the 2015 report of the Global Commission on the Economy and Climate, *Seizing the Global Opportunity: Partnerships for Better Growth and a Better Climate*. It reflects the research conducted for Section 2.1 of the full report and is part of a series of 10 Working Papers. It reflects the recommendations made by the Global Commission. The 2015 report was directed by Michael Jacobs and managed by Ipek Gencu.

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1. Introduction

We live in an urban era. Cities are growing at an unprecedented rate, particularly in the developing world: 1.4 million people are being added to urban areas each week, an area the size of Manhattan is being added every day, and by 2030, around 60% of the global population will live in cities.[1] Cities are also engines of economic growth and social change, with annual economic activity of about US$62 trillion, or about 85% of global GDP in 2015. By 2030, this is expected to rise to US$115 trillion, or 87% of global GDP.[2] Cities are also associated with 67–76% of global energy use and 71–76% of global energy-related greenhouse gas (GHG) emissions.[3]

The infrastructure investments made in cities over the next few decades will lock the world into either a higher- or lower-carbon path. Policy and financing environments need to shift significantly and quickly if cities are to move towards lower-carbon development paths. *Better Growth, Better Climate* showed how adopting more compact, connected and efficient forms of urban development would stimulate economic activity, attract investment, improve air quality and public health, enhance safety, help to reduce poverty and avoid the substantial costs associated with sprawl – all while making a significant contribution to global climate change mitigation. New analysis presented here shows that low-carbon urban actions represent a US$16.6 trillion economic opportunity worldwide. Nevertheless, it is clear that various barriers will have to be overcome if the significant economic benefits of climate action are to be realised.

This working paper outlines the critical role that international collaboration can play in accelerating and scaling up climate action in cities. It begins with a new global-scale analysis of the economic costs and benefits of urban action on climate change, then presents recent research on the direct economic impacts and the wider benefits of low-carbon investment in cities. Finally, it discusses the role of international cooperation in enabling cities to raise their ambition.

International cooperation can amplify and accelerate action by developing common platforms for action, knowledge-sharing and capacity-building, and by enhancing cities' access to finance for low-carbon development. Major cities are already seizing these opportunities through organisations such as the C40 Cities Climate Leadership Group and Local Governments for Sustainability (ICLEI), whose members have collectively agreed to emission reductions equivalent to 0.4 Gt CO_2 per year by 2030.[4] Many cities are also making ambitious commitments within new global frameworks such as the Compact of Mayors, building on related regional and country-based frameworks such as the European Covenant of Mayors and the US Mayors Climate Protection Agreement.

The paper ends with recommendations to further raise cities' climate ambition and mobilise national and international actors to support this ambition through enabling policy frameworks and financing mechanisms.[5]

2. Why low-carbon strategies are good for cities

2.1 THE ECONOMIC CASE FOR LOW-CARBON ACTION – NEW GLOBAL-LEVEL ANALYSIS

Better Growth, Better Climate demonstrates strong synergies between economic development and climate action in cities. Ambitious low-carbon policies can stimulate urban productivity and innovation, and address major policy challenges such as congestion or accessibility. Most of these opportunities need to be realised by local governments, but there is an important role for regional/provincial and national governments to create enabling policy frameworks that empower cities to invest and innovate.[6] Global cooperation is also crucial to disseminate best practice, ensure rapid collective learning, mobilise higher levels of investment, and increase ambition through credible monitoring, reporting and verification.

Building the necessary momentum at the local, regional/provincial, national and global scales depends, in part, on the presence of a compelling economic case for action. For this paper, a new global analysis was conducted looking at the direct costs, returns and payback periods of low-carbon investment in cities. The total urban population covered by the analysis is 3.6 billion in 2010, rising to 5.0 billion in 2030 and 6.3 billion in 2050.[7] The analysis builds on a recent assessment of urban mitigation potential commissioned by the UN Special Envoy for Cities and Climate Change, Michael R. Bloomberg, with support from C40.[8] That assessment covered 11 clusters of low-carbon measures in the buildings, transport and waste sectors (see Table 1), where cities have the greatest power to take action. It found that those 11 clusters could generate annual GHG savings of 3.7

Gt CO_2e in 2030 and 8.0 Gt CO_2e in 2050.[9] These emission reductions would be additional to those generated by any national policies adopted as a result of recent pledges. These savings are around 15–20% of the total global emission reductions needed for a 2°C pathway by 2030.[10] The largest 500 cities by population could contribute 1.65 Gt CO_2e by 2030, nearly half the identified urban mitigation potential.[11]

Table 1
Low-carbon actions analysed in the economic analysis

Buildings	
New building heating efficiency	New buildings are constructed at passive heating levels: <30 kWh/m² from 2020–2030 and 15 kWh/m² from 2031–2050.[12]
Heating retrofits	Old buildings are upgraded at a rate of 1.4–3% of the building stock per year, such that all existing buildings are upgraded by 2040. The retrofit reduces building energy intensity by 30–40% compared with the baseline scenario and includes heat pumps in mid-latitude countries.[13]
Appliances and lighting	Efficient lighting and appliances are aggressively deployed, based on the IEA's 2DS scenario.[14]
Solar PV	Building-mounted solar PV is ambitiously installed, based on the assumption that half of the solar PV in IEA's 2DS scenario[15] is distributed PV deployed in cities, in proportion to the regional urban population.
Transport	
Urban planning and reduced passenger travel demand	Land use planning reduces motorised passenger travel activity (pkm per capita) by as much as 7% in OECD countries and 25% in developing countries.
Passenger mode shift and transit efficiency	Expansion of public transport leads to 20% lower pkm mode share of light-duty vehicles (LDVs) and higher mode share for rail and bus transport.[16]
Passenger car efficiency and electrification	A combination of more efficient and electric private vehicles results in >45% improvement in private vehicle efficiency globally. The energy intensity impact of electrification is based on the 2DS scenario variant Electrifying Transport [17] and *Energy Technology Perspectives*.[18]
Freight logistics improvements	Freight transport logistics improvements lead to a 5% reduction in tkm per capita by 2030 and 12% by 2035.[19]
Freight vehicle efficiency and electrification	Global freight energy efficiency improves by 17% by 2030, and by 26% by 2050. In addition, 27% of global freight is electrified by 2050.[20]
Waste	
Recycling	Recycling rates rise to collect 80% of recoverable materials by 2050 in all regions by 2050.
Landfill gas capture	The fraction of methane captured rises by 5.5% annually in non-OECD countries and by 2.5% in OECD countries. All regions experience 2% annual growth in methane capture facilities that also generate grid electricity.

Source: Erickson and Tempest, 2014.[21]

Beyond those built into the International Energy Agency (IEA) 4DS scenario, this estimate of carbon saving potential does not take into account rebound effects, where savings from improved energy efficiency are used to access more energy services rather than to achieve energy demand reduction. Although rebound effects reduce overall carbon saving, it is important to note that they can be driven by positive social outcomes – for example, because savings from improved building efficiency are spent on additional heating, reducing rates of fuel poverty.[22] To evaluate the economic case for investing in the large-scale deployment of these measures, we assessed the incremental costs that cities would face if they implemented these low-carbon measures instead of their standard, higher-carbon equivalents. We then compared the additional investment needs with the

energy savings that these low-carbon measures would generate in the period to 2050, relative to business as usual.[23] A detailed description of the methods and assumptions underpinning the analysis is presented in the Appendix.

The analysis is very conservative. In contrast to previous estimates of global investment needs, including those in *Better Growth, Better Climate*, it does not consider the investment costs avoided, which are likely to be significant – for example, when better public transport reduces expenditures on new cars and roads. It also excludes savings beyond 2050, even though many measures will generate savings for much longer. In addition, the analysis does not consider action in other sectors, such as energy or industry, where local governments typically have less scope for action. Finally, the analysis presents only *direct* economic benefits, which are a fraction of the total benefits when we consider the wider social, economic and environmental impact of these investments. Those broader benefits are discussed further below.

The analysis is sensitive to the fact that the returns on low-carbon investments will be influenced by energy prices, interest rates and technological learning rates (i.e. rates of improvement in price and performance as technologies are more widely produced and adopted). The main findings are based on a central or "medium" scenario where real (i.e. after inflation) energy prices rise by 2.5% per year, real interest rates are 3% per year, and the technological learning rate for each measure is low.

Even with this focus on the low-carbon options that could be adopted or promoted by local government, and with conservative and time-limited estimates of costs and benefits, the analysis finds a compelling economic case for significant low-carbon investment in cities. In the "medium" scenario, the gross global costs of these investments would be US$977 billion per year in 2015–2050 (equivalent to 1.3% of global GDP in 2014), but they would reduce annual energy expenditure by US$1.58 trillion in 2030 and US$5.85 trillion in 2050 (see Table 2 for further information). While we must acknowledge potentially significant opportunity costs, this means the low-carbon investments collectively would pay for themselves within 16 years. The current value of the stream of net savings they would generate for cities in 2015–2050 (measured as a net present value or NPV) would be US$16.6 trillion.[24]

Table 2
Potential urban abatement and the associated economic case by sector in 2030

Sector	Measure	Annual abatement 2050 (Gt CO_2e)	Share of total abatement (%)	Energy savings (Mtoe)		Total incremental Investment[1] (2015–2050; trillion USD)	Energy cost savings[2] (2015; billion USD)		NPV[3] (trillion USD)	Average payback[4] (years
				2030	2050		2030	2050		
Buildings – residential	New building heating efficiency	1.2	15%	168	375	5.3	267	957	2.1	8.4
	Heating retrofits	0.5	7%	142	175	6.4	209	501	-0.3	20
	Appliances and lighting	0.9	11%	92	211	0.1	147	529	3.7	0.2
	Fuel switching / solar PV	0.2	3%	6	23	0.7	15.6	100	0.2	11
Buildings – commercial	New building heating efficiency	0.5	7%	77	196	6.6	120	479	-2.1	21
	Heating retrofits	0.2	3%	66	87	4.0	103	260	-0.7	23
	Appliances and lighting	0.7	8%	67	176	0.4	96.2	584	3.0	1.0
	Fuel switching / solar PV	0.2	3%	2	7	0.2	3.9	24.9	0.0	13

Sub-total buildings		**4.5**	**57%**	**619**	**1250**	**23.7**	**961**	**3435**	**6.0**	**17.4**
Transport – passenger	Urban planning: reduced travel demand	0.5	6%	56	122	-	101	553	2.9	-
	Mode shift and transit efficiency	1.0	12%	118	263	6.9	210	676	1.4	16
	Car efficiency and electrification	0.9	11%	92	207	2.5	198	777	3.8	4.9
Transport – freight	Logistics improvements	0.2	2%	15	44	-	14.6	66.0	0.4	-
	Vehicle efficiency and electrification	0.3	4%	47	99	1.0	94.4	348	2.2	4.5
Sub-total transport		**2.8**	**35%**	**328**	**735**	**10.4**	**618**	**2420**	**10.6**	**11.9**
Waste	Recycling[5]	0.3	4%	-	-	-	-	-	-	-
	Landfill gas	0.3	4%	0	1	0.03	0.7	3	0.0	20
Sub-total waste		**0.6**	**8%**	**0**	**1**	**0.0**	**0.7**	**2.6**	**0.0**	**20**
Total		**8.0**	**100%**	**947**	**1986**	**34.2**	**1579**	**5858**	**16.6**	**15.7**

[1] Undiscounted, with reference learning factors.
[2] Undiscounted, with energy prices increasing at 2.5% per year.
[3] With a 3% discount rate, with energy prices increasing at 2.5% per year, and reference learning curves.
[4] With each measure's payback weighted by total investment.
[5] It was not possible to undertake a robust economic assessment of this measure due to significant variability between different contexts. This accounts for the relatively low NPV for the waste sector in this table and in Figure 1.

Source: Analysis from the University of Leeds and Stockholm Environment Institute.

The analysis also considers the economic case under a range of different energy prices, discount rates and learning rates, as shown in Figure 1. The results suggest that the net economic returns (as expressed as a positive NPV) would be even more significant in scenarios with higher technological learning rates or energy prices. Such conditions could emerge even without enabling policies, particularly given recent energy market developments and drops in the price of key low-carbon technologies.

However, the economic case for action would be significantly strengthened through national policy interventions, such as support for low-carbon innovation, reduced fossil fuel subsidies (with supporting transition mechanisms) and carbon pricing. Under these conditions, the present value of the net savings generated by these investments would be US$21.86 trillion – and this is with a real discount rate of 5%, which offers substantial scope to secure private sector investment. In a scenario with lower energy prices and a lower technological learning rate, this bundle of measures would still have an NPV of US$4.85 trillion, with a real discount rate of 3%. This demonstrates that, even under unfavourable economic conditions for low-carbon investment, these measures still emerge as economically attractive using a standard public-sector discount rate.

The analysis also reveals significant variations in returns and payback periods across sectors. As shown in Figure 1, low-carbon investments in transport – vehicle efficiency and electrification, modal shift, and urban freight logistics improvements – have a positive NPV under nearly all scenarios, as do the residential buildings measures. This suggests that these low-carbon investments make economic sense even with low energy prices, low technological learning rates and medium to high discount rates.

By comparison, in the absence of enabling policies from government, ambitious urban actions to achieve the full mitigation potential of the commercial building and waste sectors are likely to need higher technological learning rates or higher energy

Figure 1
The net present value (NPV) of the urban mitigation scenario in the transport, buildings and waste sectors between 2015 and 2050

The net present value (NPV) of the urban mitigation scenario in the transport, buildings and waste sectors between 2015 and 20150
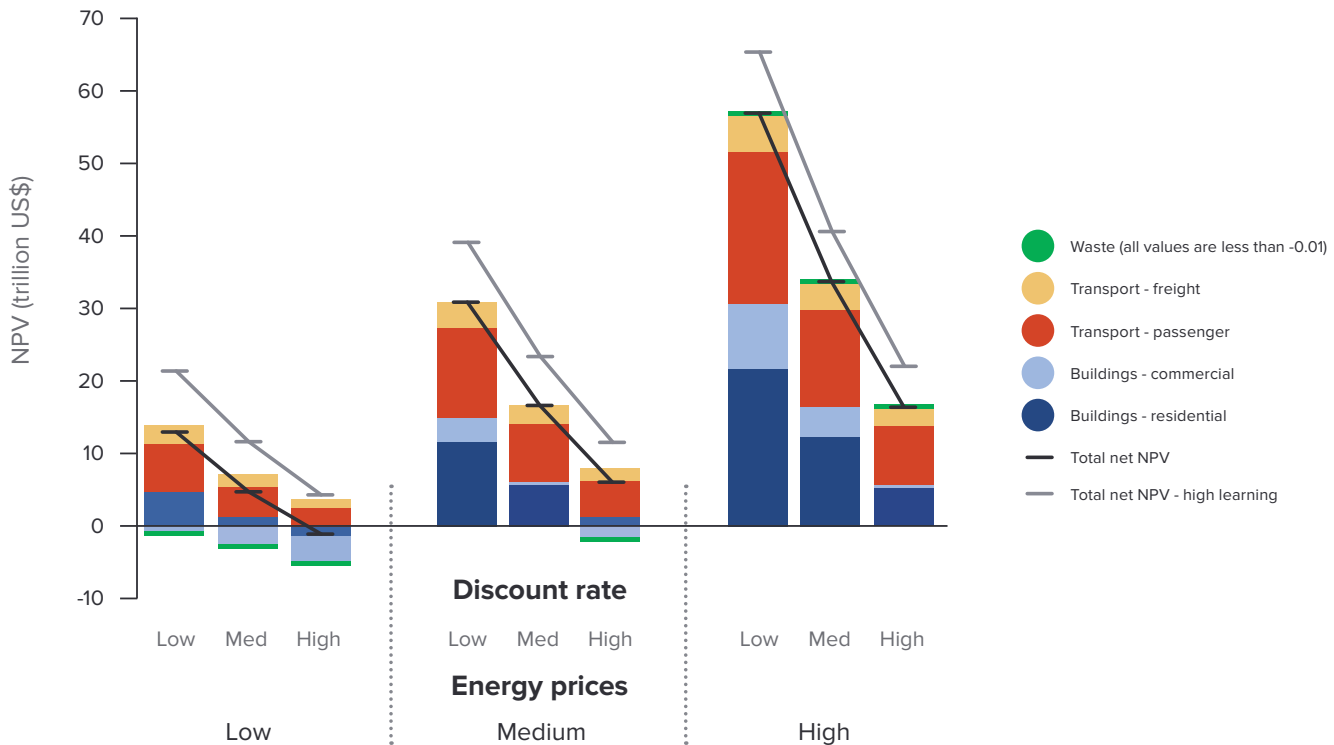
Note: Under the 'low', 'medium' and 'high' scenarios, the real discount rates used are 1.4%, 3% and 5%, and the increases in real energy prices are 1%, 2.5% and 4%. Learning rates are sector- and technology-specific.

Source: Analysis from the University of Leeds.

prices to make them attractive to private investors. The case for private investment does exist in these sectors, but it would involve less ambitious measures, such as shallower building retrofits deploying only the more cost-effective technologies. However, the case for investment in deeper retrofits could readily be strengthened through policy measures, such as mandatory energy labelling for buildings or the provision of financial support for building retrofit schemes.

Similarly, while this analysis demonstrates the aggregated economic case for pursuing city-level mitigation on a global scale, the findings are not representative of particular cities or regions. We therefore emphasise that individual cities will need to identify climate actions that are appropriate and feasible in their particular contexts.

The widespread deployment of the low-carbon measures included in this analysis is ambitious but achievable. Clearly markets will not deliver all of the change that is needed, and there will be real challenges to implementation – politically for local leaders, institutionally for municipal governments, and financially for both public and private actors, who may need to shoulder higher upfront costs. Most cities face significant indirect costs and real structural obstacles to making strategic long-term investments, given their short-term political cycles and limited legal/fiscal powers. Fast-growing cities in the developing world face additional challenges, as population growth compounds existing service and infrastructure deficits. However, these findings suggest that there is a clear, compelling economic case for cities to pursue low-carbon urban action. With creative policy instruments and innovative financing mechanisms to help facilitate these investments, cities can overcome the barriers, and realise cost savings to public budgets, residents and businesses for decades to come.

2.2 THE ECONOMIC CASE FOR LOW-CARBON ACTION

As discussed in *Better Growth, Better Climate*, the benefits of low-carbon investment in cities go far beyond the direct cost savings assessed above. Making cities more compact, connected and efficient has the potential to generate sustained urban productivity improvements and a wide range of economic, social and environmental benefits. These benefits strengthen the case for much greater climate ambition, which is crucial to ensure that emission reductions are not quickly overwhelmed by the impacts of continued economic and population growth.

The goal of this type of development is not just to contain sprawl, but to manage urban expansion in a way that encourages dense, transit-oriented and liveable urban forms. When successful, such development can unlock agglomeration effects and networking advantages, spurring innovation and productivity. It can also significantly reduce the cost of providing services and infrastructure such as public transport, energy, waste and water. And it can significantly increase the viability of public transport and other urban investments by promoting more intensive use and reducing total infrastructure requirements.[25] Analysis for *Better Growth, Better Climate* shows that compact, connected urban growth could reduce global infrastructure requirements by more than US$3 trillion between 2015 and 2030.[26] There is also emerging evidence that encouraging real estate investment into more compact, connected and vibrant urban cores can have a positive impact on long-term returns for private investors.[27]

The costs of not pursuing more compact urban development are also significant. Congestion alone imposes immense costs on many cities due to lost work hours, reduced labour mobility, increased expenditure on fuel, and health costs from air and noise pollution. As a proportion of regional GDP, the costs of congestion are estimated at 1.1% for New York,[28] 1.5% for London,[29] 4.0% for Cairo,[30] 4.8% for Jakarta,[31] 7.8% for São Paulo,[32] and up to 15% for Beijing.[33] Similarly, traffic accidents kill around 1.25 million people annually, more than 90% of them in developing countries.[34]

In addition, urban sprawl imposes huge public and private costs by increasing transport expenditure on transport and grid infrastructure (e.g. electricity, waste and water), raising levels of air pollution, discouraging walking and cycling, impacting on public health, reducing the efficiency of primary services such as education and health care, and reducing the availability of land for agriculture and ecosystem services. For example, recent analysis for the Commission suggests that the costs of urban sprawl to the US economy exceed US$1 trillion per year, or around 2.6% of GDP in 2014.[35] The World Bank estimates that China could save up to US$1.4 trillion in infrastructure spending to 2030, or around 15% of GDP in 2013, if it pursued more compact, transit-oriented urban development.[36]

Countries and cities that are planning for or experiencing rapid urban development could learn from cities that have invested in strong, connected, accessible public transport systems. A new study by PwC explored the relationship between the economic performance of 30 global cities and the presence of effective public transit networks, finding that cities that are better connected by public transport are more productive, have greater purchasing power, achieve a better overall quality of life, and attract more top companies and foreign direct investment.[37] The Intergovernmental Panel on Climate Change (IPCC) has suggested that, over the medium- to long-term, making cities more public transport-oriented and compact, combined with improving infrastructure for non-motorised transport, could reduce GHG intensities by 20–50% compared with 2010 levels.[38] For example, despite similar wealth levels and population sizes, Atlanta's carbon footprint is more than five times higher than Barcelona's due to past transport infrastructure and planning decisions.[39]

2.3 THE ECONOMIC CASE FOR LOW-CARBON ACTION – LATEST CITY-LEVEL ANALYSIS

The new global analysis outlined in Section 2.1 above shows that low-carbon urban actions represent a US$16.6 trillion economic opportunity worldwide, based only on the energy savings that can emerge from low-carbon investments. This analysis of the direct economic savings of low-carbon action at a global scale is supported by evidence from city-level case studies. As reported in *Better Growth, Better Climate*, the results of bottom-up studies on the economics of low-carbon investment in six cities – Recife, Brazil; Kolkata, India; Palembang, Indonesia; Johor Bahru, Malaysia; Lima, Peru; and Leeds, UK – reinforce those of the global analysis. The studies highlight the extensive opportunities for cities to invest, at scale, in economically attractive low-carbon measures (for example, in building energy efficiency, small-scale renewables and more efficient vehicles) that could generate a positive financial return over their lifetime.[40]

Notably, the studies found that very different sets of measures are economically attractive for each city, depending on energy prices, policy frameworks, institutional capacities, infrastructure deficits and other local conditions. However, in all six cities there is a compelling case for large-scale investment in climate action at a real interest rate of 5%, which suggests potentially

significant private returns. The studies show that each city could achieve emission reductions in the range of 14–24% by 2025, relative to business as usual, just by exploiting the economically attractive options. These investments would yield significant annual financial savings equivalent to 1.7–9.5% of annual city-scale GDP in 2025. And while the incremental investment needed to unlock these returns is significant, averaging US$3.2 billion across the six cities, the payback period for this package of investments would be less than five years in all cities.

This analysis is corroborated by other work completed for *Better Growth, Better Climate* that looked at the benefits of low-carbon city districts in the US, China and the Middle East. That work suggests that many city-level low-carbon investments can break even after 3–5 years, generate internal rates of return of up to 30% and reduce energy costs by up to 36%.[41]

While the analysis of the direct economic benefits of climate action at the city level is conclusive in demonstrating the economic case for urban climate action, this is not the whole story. As also outlined in Section 2.2, the benefits of low-carbon urban investments go well beyond cost savings. They can also help cities to address other priorities, such as increasing mobility, reducing poverty or improving health outcomes. To support the evidence presented above, we present five recent case studies that illustrate the potential for city-scale climate actions to generate a wider range of economic, social and environmental benefits, if they are designed and delivered with care.

Case 1: Making new buildings more energy efficient

As outlined in Table 1, globally, measures in the buildings sector represent over half of the urban mitigation potential in the period to 2050. Cities need an estimated 70,000 km^2 of new residential floor space by 2030, equivalent to 60% of the world's current residential floor space.[42] Accelerating energy efficiency in new residential buildings is therefore of huge significance, and many cities are accordingly establishing municipal green building codes that far exceed national standards, including Pune in India, San Francisco in the US and Shanghai in China.

New analysis of green building standards in Recife, Brazil, by the University of Leeds indicates that such standards can pay for themselves quickly. If meeting "passive cooling" standards entails incremental investment needs of 3%, investors would recover their costs through energy savings in 6 years in commercial buildings, 7 years in public buildings, and 18 years in residential buildings, where a smaller share of total electricity consumption is for cooling purposes (see Table 3). After paying for themselves, such investments would generate savings throughout the 40+ years of each building's lifespan. This kind of programme has already been implemented in Singapore, which aims to have 80% of its buildings achieve the Green Mark standard by 2030.[43] This could potentially reduce building electricity use by about 22%, with net economic savings of over US$400 million.[44] These investments to "green" buildings have been estimated to pay for themselves in less than 6 years and have the potential to increase property values by 2%.[45]

However, the evidence suggests that innovative green building design can yield much broader benefits, including expanding green space, reducing heat island effects, filtering air pollution, and capturing rainwater to reduce demand for piped water. With these kinds of improvements, green buildings are thought to improve pupil learning and teacher satisfaction in schools,[46] support faster recovery rates in hospitals,[47] and improve employee productivity in offices.[48]

Table 3
The value of green building standards in Recife, Brazil, in 2030

	Energy savings (GWh / % of BAU sector electricity consumption)	Emission reductions (1000 t CO$_2$ / % of BAU sector emissions)	Economic savings in 2030 with a 2% real energy price increase (USD millions)	Payback period with a 5% interest rate (years)
Commercial	404.5 / 13.7%	45.5 / 16.4%	64.92	6
Public	119.7 / 4.0%	13.5 / 16.5%	16.55	7
Residential	58.0 / 2.54%	6.5 / 1.5%	10.78	18

Source: Analysis by the University of Leeds.

Case 2: Retrofitting existing buildings

Retrofitting existing buildings is as important to urban climate action as improving energy efficiency in new buildings. Several mature cities have initiated large-scale retrofit schemes to realise the multiple benefits of more efficient buildings. Again, while the direct energy savings are important, unlocking the wider benefits is equally crucial. Although the incremental costs of retrofit can pose a significant barrier to deployment, robust financing mechanisms can overcome these barriers to unlock both the direct economic savings and the wider benefits.

One promising solution is a revolving fund that invests in energy efficiency, and captures and reinvests some of the savings generated by its early investments. Such funds can be adopted in different ways, with different impacts. Recent work on the Leeds City Region in the UK considered the potential of a revolving fund to finance domestic building retrofits. Similar models include the Thai Energy Efficiency Revolving Fund and the New York State Drinking Water Revolving Fund. The analysis considered funds of three different kinds: a private, profit-led fund where only measures that generate direct net economic savings to the private sector are funded through loans offered to households at a 7% interest rate; a public–private partnership (PPP) where only measures that generate direct net economic savings to the private sector are funded, but with subsidised loans to households at a 3.5% interest rate; and a not-for-profit, government-led scheme where all available measures are funded through interest-free loans to households.[49]

Analysis shows that the profit-led fund results in cumulative mitigation by 2050 of 6.5 Mt CO_2 — only around half that of the PPP or not-for-profit scheme – but that the profit-led fund would recoup initial investments in less than 20 years, while the PPP scenario would take an estimated 37 years and the not-for-profit scheme would suffer a financial loss. However, when the wider economic benefits of a retrofit programme are considered, both the PPP and the not-for-profit schemes become more economically attractive. In the UK, for example, it is estimated that every UK£1 spent on reducing fuel poverty can save the National Health Service UK£0.42 in health costs.[50] For Leeds City Region, if investments targeted the 10% of households in fuel poverty, the PPP and non-profit schemes would lead to health care savings of UK£80–100 million. Moreover, the increased economic activity from job creation and reduced energy bills that a retrofit scheme would generate would increase tax returns for the government by UK£1.27 for every UK£1 invested.[51] In this way, a building retrofit scheme becomes a very economically attractive option for the public sector when taking into account the significant wider social and economic benefits.

Case 3: Expanding and improving mass transit

As outlined in Table 1, globally, measures in the transport sector represent over a third of the urban mitigation potential in the period to 2050. The transport sector is the fastest-growing consumer of fossil fuels and producer of GHG emissions globally.[52] However, even the most sprawling cities have opportunities to shift from individual motorised transport modes to low-carbon options. This will unlock not only direct net economic savings, but also far wider benefits. Local governments are already showing creativity and ambition in urban transport, as illustrated by the proliferation of bus rapid transit (BRT) systems. This option appeals to local governments because of the relatively low investment needs: one study found that the capital costs of BRT averaged about US$10 million per mile in 1990 dollars, less than half the cost of light rail transit or a tenth of metro rail transit.[53]

Curitiba, Brazil, and Bogotá, Colombia, are the pioneers and success stories, but BRT systems are increasingly being adopted in more challenging contexts that require innovative political engagement and financing mechanisms. Rea Vaya in Johannesburg, the first full BRT system in Africa, is a good example. In Phase 1A, Rea Vaya had an average daily ridership of 40,000. Prior to its construction, about 70% of public transit between Soweto Township and the Central Business District involved overloaded, poorly maintained 16-person minibus taxis with haphazard schedules. A participatory decision-making process during the design phase engaged key stakeholders, including the minibus operators, who went on to become bus drivers and shareholders in the BRT system. Although Rea Vaya continues to face challenges, particularly strikes from disaffected drivers, the NPV of Rea Vaya Phase 1A is US$143 million, just based on direct economic returns.[54] When the wider benefits of improved road safety and mobility are considered, particularly among poorer populations, the NPV rises to nearly US$900 million (Table 4).[55] There is a need for ongoing domestic leadership and international collaboration to improve the efficiency and equitability of the Rea Vaya BRT system, but this example demonstrates the potential wider benefits of ambitious climate action.

One way to generate funding for mass transit is through congestion pricing. First implemented in Singapore in 1975, it has been adopted in several other cities since, including London, Stockholm and Milan. In London, the congestion charge reduced vehicle traffic by 16%, traffic delays by 26%, and journey times by 14% in the first three years[56] – with minimal impacts on local business.

Table 4

The monetised benefits of the Rea Vaya BRT system in Johannesburg, South Africa

Components of benefit/cost	Net present value (USD millions 2012)
Travel time savings	331
Improved road safety	268
Increased physical activity	141
Operating cost reduction	170
Travel time lost during construction	-38
CO_2 emissions reduction	18
Total	**892**

Source: Analysis by WRI EMBARQ research team (Carrigan et al., 2014).

Particulate matter and nitrous oxide emissions have been reduced by 12%, leading to an increase in life expectancy of 1.83 years for every 1,000 people living within the congestion charge zone,[57] and raising £235 million in net revenue each year for further transport investments.[58] Major cities now considering or developing similar programmes include New York, Beijing, Guangzhou and São Paulo, suggesting that this financing mechanism could appeal to urban decision-makers in both the developed and developing world.

Case 4: Promoting cycling

Like bus rapid transit, cycling has multiple benefits for cities. It costs far less than motorised travel, both for the public and in terms of infrastructure investment needed. Cities with convenient cycling infrastructure benefit from significant health care savings from increased physical activity, reduced air pollution levels and reduced road fatalities.[59] Importantly, cycling is an equitable transport mode that can enhance mobility for the urban poor and increase interaction among nearly all groups.[60] There are therefore compelling economic, social and environmental reasons for cities to invest in safe and well-connected cycling infrastructure.

Recent analysis of the costs and benefits of cycling in Copenhagen, Denmark, found that the net social gain is US$0.21 per cycled kilometre, mostly from health care cost savings. This compares with a net social cost of US$0.12 per driven kilometre.[61] Accounting for indirect benefits in this way means that Copenhagen's planned Cycle Super Highways are estimated to have an internal rate of return on investment of 19% per year.[62]

While it can be difficult to retrofit cycling infrastructure into mature cities, there is scope for fast-growing cities in developing countries to leapfrog the hyper-motorisation of transport that has proven so costly and unsustainable in many OECD countries. Local authorities in these contexts should therefore prioritise the development of good pedestrian and cycling infrastructure, and ensure that future transport investments enhance the safety and convenience of non-motorised options.[63]

Case 5: Increasing distributed energy generation

Cities worldwide are increasingly considering the introduction of distributed energy systems based on small-scale renewables, particularly as costs have fallen dramatically in recent years due to technological learning. In 2013, the cost per MWh of rooftop solar fell below retail electricity prices in several countries, including Australia, Brazil, Denmark and Germany.[64] Moreover, such systems help to ensure city-wide energy security in the face of volatile prices, and increase community ownership over their own energy provision – financially and politically.[65] Moreover, there are many examples of schools, universities, hospitals, social housing providers, cooperatives and councils collectively funding distributed energy systems.

The transformative impact of distributed energy is illustrated by Freiburg, Germany. The city showed early leadership on renewable energy and energy efficiency, largely driven by civil society opposition to nuclear energy. This has unlocked

considerable economic benefits for the city. It has dramatically increased energy security – 50% of local electricity needs are now met by over 100 combined heat and power (CHP) plants around the city,[66] and a further 6% by wind turbines and solar panels within the city. But it has also created a significant number of jobs as a result of investment in renewable energy, and it has helped to galvanise wider climate action across the city. For example, the municipality and the citizens have extended their pioneering climate actions to the transport and building sectors: 420 km of cycle tracks allow 35% of residents to live without a car, while all new houses are built to high energy efficiency standards. As a result, the green economy in Freiburg now employs 12,000 people – almost 3% of the city's work force.[67]

2.4 SUMMARY

The new analysis presented above shows that there is a strong economic case for investing in low-carbon strategies. Low-carbon investments in the buildings, transport and waste sectors can more than pay for themselves over their lifetime and generate direct economic savings for cities currently valued at US$16.6 trillion, and with supporting policies could be as high as US$21.8 trillion. As new measures, such as smart grids, and innovations by the private sector are refined and deployed at scale, the scope for economic and carbon savings could be even higher.

The analysis also shows that investments in low-carbon cities could generate wider economic, social and environmental benefits in the form of improved levels of equality, health, education, employment, innovation, productivity, mobility and environmental quality. They could also create new revenue streams and reduce the need for government expenditure. However, cities face many barriers to realising these benefits. Local authorities therefore need the support of national governments to alleviate governance and budgetary bottlenecks, and of international actors to help to scale up and accelerate action.

3. International cooperation to support low-carbon urban strategies

Many cities are leading on climate change, and delivering significant economic and social benefits in the process. Where these cities face barriers to action, international networks such as C40, ICLEI and United Cities and Local Governments (UCLG), and international actors such as the multilateral development banks and United Nations agencies, are supporting cities to go further and faster. Yet collaboration is needed on a much greater scale to realise the huge economic and climate potential discussed above. Alongside other major processes this year, the UN Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador in 2016 will be another major moment to consolidate and accelerate international collaboration to respond to the challenges of urbanisation. The consultations for this paper found remarkable consensus among urban development practitioners and prominent international organisations and networks on the need for collaboration in five mutually reinforcing areas:

1. Facilitating knowledge-sharing among cities on policy reform and innovation to inform and inspire action;

2. Utilising common platforms and standards to enable cities to make their commitments public, credibly record their energy use and GHG emissions, develop low-carbon strategies, and measure their results;

3. Building the capacity of local governments, so that political leaders and municipal staff can effectively plan, design and execute low-carbon development plans and strategies;

4. Financing low-carbon urban infrastructure by improving cities' access to domestic and international financial markets; and

5. Supporting national governments to empower cities to invest and innovate.

3.1 KNOWLEDGE-SHARING AMONG CITIES

Delivering ambitious emission reductions or low emission development targets in cities will demand creativity and innovation. Many cities are pioneering new climate policies, low-carbon technologies and sustainable infrastructure solutions. To realise the full potential of low-carbon action, local governments will need to build upon and learn from one another's successes. This calls for knowledge-sharing among cities on a much greater scale than currently seen.

International cooperation can support decision-makers by facilitating knowledge transfer and mutual learning. City networks such as C40, ICLEI and UCLG connect people who are tackling similar challenges and opportunities and enable them to learn

from others' experiences and adapt solutions to their own unique situations. Bogotá officials, for example, visited Johannesburg and helped to convince the city that a BRT system was a much better investment than an underground train. The importance of such learning is clear. Since Curitiba, Brazil, piloted the BRT system in the 1970s, more than 190 cities have followed suit, so BRT systems now cover more than 5,000 km, with over 32 million passenger trips per day.[68] Similarly, since Paris pioneered a bicycle sharing scheme in 2010, 639 cities with an estimated 643,000 bicycles have emulated its example.[69] Peer-to-peer learning, supported by international city networks, is essential to achieve scale and build upon successes.

Peer learning could be even more powerful if it is focused on helping cities to overcome key barriers, such as financing options and business models for low-carbon growth. Cities around the world are piloting innovative systems to make financial frameworks greener and unlock investment for low-carbon options. Johannesburg, South Africa, and Gothenburg, Sweden, have issued green bonds to fund low-carbon infrastructure; Hyderabad, India, and Edinburgh, UK, are trialling tax increment financing to capture land value improvements from public infrastructure investments; five cities in China and two cities in Japan have established municipal emission trading schemes. Many other cities are eager to learn from the experiences of these front-runners. While platforms such as C40's Sustainable Infrastructure Finance network and ICLEI's Green Urban Economy programme help to meet this need, opportunities for knowledge-sharing among cities should be increased, particularly between cities with similar power structures, density profiles and/or climatological opportunities and constraints.[70]

3.2 COMMON PLATFORMS FOR ACTION AND MEASURING RESULTS

International cooperation can encourage cities to raise their ambitions and enable them to credibly track their progress towards low-carbon goals. There is significant scope for more cities to make firm emission reduction commitments. In addition, a much greater emphasis needs to be placed on setting targets past 2020 or 2025 – indeed a trend is starting to emerge among cities for a long-term goal of 80% GHG reductions by 2050, sometimes known as 80x50.

Long-term decarbonisation targets are important, as they will help shape the land use and infrastructure investment decisions taken in the next 5–15 years, which will largely lock in the ability of cities to sustain emission reductions over time. There is much scope for improvement with city-scale emissions inventories as well. A recent survey of more than 100 major cities worldwide found that 60 had published data on their carbon emissions.[71] While this is encouraging, only 29 of these cities had an emissions breakdown by scope and sector, and most breakdowns were not comparable. As a result, many cities are unable to set out evidence-based plans for low-carbon action or to be formally included in their countries' "intended nationally determined contributions" (INDCs).

Even in cities with public commitments, the levels of ambition are often not well known or understood. Through international cooperation, standardised methodologies and frameworks have been developed to support urban action. Notable among these is the Compact of Mayors, a major new global collaboration of mayors and city officials focusing on climate change. It encourages cities to take ambitious local climate action, following a logical but flexible progression over a three-year period. This involves (i) committing to addressing GHG emissions; (ii) producing an emissions inventory using a consistent and robust standard (the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories); (iii) setting targets for carbon reduction, which can act as a "floor" on ambition and which can be raised over time with technological progress; and (iv) developing an action plan to deliver these targets.

As of June 2015, 80 cities had formalised their commitment by joining the Compact of Mayors. The initiative is led by C40, ICLEI and UCLG, and supported by UN-HABITAT, the World Resources Institute, CDP and the UN Special Envoy for Cities and Climate Change, Michael R. Bloomberg.

One of the Compact's primary objectives is to enable recognition of new and existing city-level commitments made through other important initiatives. This will make it possible for the first time to consolidate commitments that cities have already made in a single place, while encouraging greater ambition and allowing for consistent measurement and tracking of progress and impact. These include the US Mayors Climate Protection Agreement (2005), the EU Covenant of Mayors (2008), Making Cities Resilient Campaign (2010), the Global Cities Covenant on Climate: The Mexico City Pact (2010), the Durban Adaptation Charter (2011), the US Mayors National Climate Action Agenda (2014) led by Mayors Annise Parker (Houston), Eric Garcetti (Los Angeles) and Michael Nutter (Philadelphia), among others. The Covenant of Mayors in Europe, for example, already has more than 6,000 signatories who have set emission reduction targets and adopted sustainable energy plans to help meet them, with a well-established set of guidance and financial mechanisms to support action. Under the US Mayors Climate Protection Agreement, 1,000 mayors have committed to climate action.

The use of standard frameworks, methodologies and reporting platforms increases the credibility of cities' climate commitments. This, in turn, can unlock technical and financial assistance from supporting institutions, including multilateral development banks and agencies. As with other global city-related performance metrics and indexes, this type of international initiative also helps to promote a "race to the top", with cities not only collaborating but also competing in the global race for capital, by using low-carbon strategies as the platform to boost their attractiveness as places to live and do business. The use of standard frameworks is also supporting leadership by governments at the regional and provincial levels, which is helping to complement action at the municipal level, including through a new international Compact of States and Regions formed in 2014 (as outlined briefly in Box 1).

Common platforms at the regional level can complement city level climate action

Regional and provincial governments and actors can also play an important role in driving low-carbon development. California (9th), Jiangsu (17th), and Sao Paulo (25th) are among the largest economies in the world, and regions such as Uttar Pradesh, Maharashtra and Guangdong each govern more than 100 million people.[72] In critical policy areas, such as energy regulation and finance, states and regions often have important responsibilities for both implementing national policy and enabling city policy.

Last year, alongside the Compact of Mayors, leading state and regional networks including The Climate Group States and Regions Alliance, Regions of Climate Action (R20), and Network of Regional Governments for Sustainable Development (nrg4SD), in partnership with the CDP, launched the Compact of States and Regions. This is the first global platform for state and regional governments worldwide to report their climate targets and progress in a standardised way. Nineteen regional governments across 11 countries joined in just the first few months. A complementary initiative, the Global Climate Leadership Memorandum of Understanding (Under 2 MOU), encourages subnational jurisdictions to come together to make ambitious emission reduction commitments. Eighteen states and provinces have already joined, committing to reducing their emissions by 80–95% by 2050; they represent 130 million people and US$5.3 trillion in GDP.[73] A number of states and regions are also cooperating together on emissions trading, with over 20 sub-national jurisdictions having implemented or scheduled to place a price on carbon. They include the nine states of the US and Canada which since 2009 have combined under the Regional Greenhouse Gas Initiative to implement a regional carbon budget for power sector emissions.[74]

Many states and regions are using their economic development powers to support new clean technology markets and to leverage private climate finance. For example, Upper Austria's Sustainable Energy Cluster, which focuses on supporting clean energy and energy efficiency companies, has grown from 74 to around 200 companies and partners since 2000, and from US$250 million to $2.5 billion in annual turnover – about 4% of the region's total GDP.[75] In 2013, Connecticut's Green Bank used US$40 million in public funds to attract US$180 million in private capital for new clean energy projects; it has a 9:1 private to public investment ratio, and is creating more than 1,200 new jobs.[76] Many similar examples are now being developed in states and regions around the world.

3.3 BUILDING CAPACITY TO ACT

Technical capacity to understand and address climate risks is a challenge for governments at all levels, and it is particularly acute at the local level. As illustrated by the examples in Section 2, there is great potential for low-carbon actions at the local level, but national governments may not recognise it. They also may not realise the significant demands that local authorities face, often with limited resources. As a result, there is a strong tendency to give too low a priority to training and support for local government staff. This needs to change so that local authorities have the tools and knowledge they need to devise and implement low-carbon development strategies.

International cooperation can make a major difference in this regard – in particular, in supporting local authorities to understand the science, the economics, the policy options and the business models most relevant to unlocking low-carbon growth. According to the World Bank, only about 20% of the 150 largest cities in the world have even the most basic analytics needed for low-carbon planning.[77] International actors can provide training for municipal staff and political leaders responsible for designing policies and making key infrastructure investments. This is particularly important in emerging and developing economies, where there is also a need to professionalise capacity-building initiatives in these countries.

The Leaders in Urban Transport Planning (LUTP) programme illustrates best practice. This initiative helps senior and mid-level transport professionals develop a structured approach to decision-making through a series of group exercises, case studies and site visits. The focus during the self-learning phase (five weeks) and workshop (seven days) is on understanding the complexities of urban transport problems and on building the skills for integrated mobility planning. This hands-on approach is supplemented by twinning and mentoring schemes, so that participants benefit from ongoing support and guidance.[78] So far, the LUTP programme has been delivered in 12 cities in developing and emerging economies.

International actors can also help cities to create institutional and organisational environments that support effective urban management – for example, by helping to establish integrated municipal authorities to address cross-cutting challenges such as effective land use and transport planning.[79] Finally, both national and international actors can support local decision-makers by collecting climate-relevant data at the city level. This information can help cities to design effective strategies for managing and reducing their GHG emissions.

The City Planning Lab (CPL) initiative in Indonesia illustrates how international collaboration can support both institutional development and data collection. Each CPL is a dedicated facility for spatial analysis and urban planning. The CPLs provide "just in time", demand-driven data to feed into the decision-making of their city, as well as coordinating urban management functions, such as the issue of building permits. As local technical capacity strengthens, external involvement will diminish.[80] The first CPLs have been implemented in Surabaya and Denpasar, and the next stage will launch in Palembang and Balikpapan.

3.4 FINANCING THE LOW-CARBON TRANSITION

While low-carbon urban strategies have direct and wider economic and social benefits, unlocking these benefits does require investment. Although additional costs are often small in relation to aggregate investment needs, and payback periods are short, the extra finance needed can be significant from the perspective of resource-constrained municipal authorities. Cities too often rely on narrow revenue bases that do not have sufficient fiscal space for investment in large-scale urban infrastructure. Total revenues of Indian local governments, for example, amounted to less than 1% of GDP in 2007–2008.[81]

Given the budgetary deficits and significant debt levels of many national and local governments, most cities will need to engage the private sector – and in the case of developing and emerging economies, also secure climate finance – in order to cover the higher upfront costs of climate-smart urban infrastructure.[82] International cooperation can help local governments to mobilise private finance in two key ways.

First, international actors can provide technical assistance to help cities to identify, develop and implement "investment-ready" programmes or projects that have appropriate levels of risk and return. Cities worldwide currently face significant skills gaps relating to project finance, commercial advice and procurement support.[83] Technical assistance that helps cities to develop "investment-ready" programmes and projects can then leverage much larger levels of finance from global banks, investment funds and development finance institutions. This technical assistance could be hugely valuable, as every US$1 million invested in project preparation could yield US$20–50 million in capital support for successful projects.[84]

The technical assistance and support can take various forms, from supporting the development of enabling policy frameworks, to technology transfer or project feasibility analyses. To illustrate, a group of C40 cities recently came together to commit to procure 40,000 new clean buses by 2020 to drive down costs and help create economies of scale for a new, relatively novel technology.[85] Drawing on lessons from initiatives such as the Cities Development Initiative for Asia (CDIA) could also be instructive.

Second, international actors can help cities to improve their creditworthiness and thereby mobilise resources in both domestic and international financial markets. According to the World Bank, only 4% of the 500 largest cities in developing countries are deemed creditworthy in international financial markets, rising to 20% in local markets. However, investing US$1 in improving the creditworthiness of cities can leverage more than US$100 in private finance for low-carbon urban infrastructure.[86] Kampala, Uganda, for example, managed to increase locally generated revenue by 86% within a year, almost doubling what the city can borrow for large-scale urban infrastructure, and has recently secured a credit rating.[87] Similarly, Lima, Peru, secured a credit rating that allowed it to co-finance its BRT system with a loan from a domestic commercial bank. The BRT was also supported by the World Bank and the Inter-American Development Bank.[88] To allow more cities to mobilise private finance, emerging international collaborative initiatives, such as the World Bank-led Creditworthiness Initiative and the Cities Climate Finance Leadership Alliance (launched at the 2014 Climate Summit to catalyse and accelerate additional capital flows to cities[89]), should be scaled up and strengthened.[90]

3.5 EMPOWERING CITIES

Cities can make much more ambitious climate commitments if national governments give them the legal power and institutional support they need to invest and innovate. Cities in different countries – sometimes even within the same country – can be in very different positions. Some have significant budgets that they fully control, while others are more dependent on regional or national level authorities. International institutions can support countries to increase critical powers at the municipal level, and help cities understand how to make better use of the powers they already have, based on global best practice.

As highlighted in *Better Growth, Better Climate*, coordination between city departments ("horizontal integration") and between city, regional and national policy frameworks ("vertical integration") is also critical. The experiences of cities such as London and Curitiba demonstrate the particular advantages of integrated authorities to coordinate land use planning and integrated urban mobility systems.[91]

Some countries, such as China and India, are already recognising the critical role of cities in driving economic development, and are prioritising urban planning and investment in their national development strategies. In many other countries, much more needs to be done. National governments need to recognise the importance of managing urban growth well, and the potential for improving economic, social and environmental performance and alleviating poverty. This is particularly important in countries with relatively low levels of urbanisation, which have an opportunity to leapfrog high-carbon pathways and jump straight to a low-carbon urban future.

For example, by 2050, urban areas in sub-Saharan Africa will be home to 800 million more people than in 2014. Recent research for the Global Commission shows that continuing with the current model of urban development will mean that Africa's cities become increasingly polluted, socially polarised and carbon-intensive.[92] There is thus a need for effective national planning to realise the potential benefits associated with well-managed urban growth.

International organisations can help capacity-constrained countries to manage rapid urbanisation by, for example, taking a "systems of cities" approach that develops secondary cities based on major economic, environmental and social considerations. That is one of the options explored by the Global Commission's Ethiopia Partnership, led by the Ethiopian Development Research Institute (EDRI) and the Global Green Growth Institute (GGGI) in close collaboration with the Government of Ethiopia.[93]

4. Conclusions and recommendations

The economic case for low-carbon urban development is compelling. Even with very conservative assumptions, the current global value of that opportunity could be US$16.6 trillion by 2050. And that value could increase significantly, and the payback periods on the investments could shorten substantially, with effective national and international support and continued leadership by cities. In addition, there is a compelling wider economic case for transformation towards a more compact, connected and efficient urban development model. As *Better Growth, Better Climate* shows, this model can also make cities more productive, socially inclusive, resilient, cleaner, quieter and safer.

The decisions that cities take within the next 15 years will be critical to capturing these benefits. International cooperation led by nations and cities and supported by international organisations is needed to amplify and accelerate action.

The Global Commission on the Economy and Climate therefore recommends that all cities commit to developing and implementing low-carbon urban development strategies by 2020, using where possible the framework of the Compact of Mayors, prioritising policies and investments in public, non-motorised and low-emission transport, building efficiency, renewable energy and efficient waste management.

City and local governments should demonstrate leadership by committing to ambitious emission reduction targets and/or low-emission development strategies, aiming to be compliant with the framework of the Compact of Mayors by 2020.[94] This should include building the skills of political leaders and municipal staff to plan, design, finance and deliver low-carbon development plans, and improving coordination of transport and land use decisions by integrating the authorities.

National governments should empower cities to innovate and invest in low-carbon action, by:

- Introducing national legislation to support and incentivise the adoption of emission reduction targets and/or low-emission development strategies; this should include creating channels for cities with low-carbon strategies and accountable governance systems to engage directly with national development banks;

- Developing national urbanisation strategies in conjunction with city governments, overseen by a high-level executive authority and/or the Ministry of Finance, with cross-departmental representation to enable integrated planning and assigned budgets to ensure adequate resourcing; such strategies should include establishing financial and legal infrastructure that favours low-carbon investment;

- Where local authorities do not have critical powers to act, consider adopting reforms to expand their powers, particularly with regard to land use management, local energy and transport systems and public finance; such reforms should be complemented by appropriate fiduciary safeguards, so that cities can invest in economically attractive low-carbon urban infrastructure.

The **international community** – including development agencies and other sources of city finance, city networks and organisations, and multilateral and regional development banks – should help to accelerate and scale up low-carbon urban strategies by developing an integrated package of US$1 billion or more over five years to:

- Support at least the world's largest 500 cities by population – which represent half of global urban mitigation potential up to 2030 and over half of global GDP[95] – to comply with the Compact of Mayors by 2020, by providing technical assistance and resources of at least US$500 million to the relevant bodies.[96] This should include a mixture of development finance, philanthropic capital and other sources of funds, and should be targeted at building on existing efforts by cities, using their own resources, and at filling critical resource gaps in smaller and developing cities.

- Provide cities with increased technical assistance and capacity-building for project preparation to enable them to identify, develop and implement "bankable" programmes and projects for low-carbon, climate-resilient urban infrastructure. One option for delivering this would be through the creation of a project preparation support fund of at least US$250 million to support – at a minimum – the world's largest 500 cities by 2020. This package could directly mobilise at least US$5–10 billion in private investment through project preparation support, and leverage further large-scale capital to support a low-carbon urban transition.[97]

- Enable cities to mobilise private finance for urban infrastructure investment, including by scaling up the World Bank-led City Creditworthiness Initiative to reach at least the world's largest 500 cities by 2020 by ensuring resourcing of at least US$375 million,[98] strengthening the Cities Climate Finance Leadership Alliance, and scaling up opportunities for cities to receive credit enhancement from the multilateral development banks.

- Enable cities in developing countries to catalyse low-carbon investment by directly accessing climate finance – for example, through dedicated windows in the Green Climate Fund and Global Environmental Facility and direct access to finance through the multilateral development banks. This would help cities to cover incremental upfront costs of low-carbon options and to leverage private capital, where cities have demonstrated sufficient fiduciary safeguards and where this is agreed in partnership with nation states. Access to such funding opportunities should be quick, efficient and transparent, avoiding unnecessary administrative burdens for city authorities.

- Provide enhanced platforms for knowledge-sharing and technology transfer among cities – for example, through supporting global city networks such as C40, ICLEI and UCLG.

Implementing these recommendations – through a combination of policy measures and investments by cities in key sectors, acting with support from nation states and enhanced by international collaboration – could deliver at least 3.7 Gt CO_2e in emission reductions, or 15–20% of what is needed in 2030 to bridge the gap to a 2°C pathway. This is a chance to make a real difference for the climate – and at the same time, seize at least a US$16.6 trillion economic opportunity.

ENDNOTES

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9 For the emissions potential estimates, see Erickson and Tempest, 2014. *Advancing Climate Ambition: How City-Scale Actions Can Contribute to Global Climate Goals*.

If under "business as usual" trends, less ambitious action takes place than planned by nation states – such as under the IEA's 6DS scenario – mitigation potential in cities could be even higher than this. See: *Technical Note: Quantification of the Emissions Impact of the NCE Recommendations*, 2015 (forthcoming). To be available at: http://newclimateeconomy.report.

10 UNEP, 2014. *The Emissions Gap Report 2014*. United Nations Environment Programme, Nairobi. Available at: http://www.unep.org/publications/ebooks/emissionsgapreport2014. The report assumes a median emissions gap verses existing policies and pledges of 14–17 Gt. In contrast, if the baseline is assumed to be the IEA's 6DS scenario, which is an extension of current emission trends, rather than the 4DS scenario, which includes recent national pledges and policies to limit GHG emissions, the emissions gap would be around 22 Gt.

For a summary of the IPCC's median 2°C scenario of 42 Gt in 2030 and the assumed baseline of 64 Gt, which suggests an emissions gap of 22 Gt in 2030, without including national pledges and policies to limit GHG emissions, see also: *Technical Note: Quantification of the Emissions Impact of the NCE Recommendations*, 2015.

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44 Figures provided by the Singapore government to New Climate Economy based on findings from the national energy technology roadmap for Building Energy Efficiency developed by the Energy Research Institute at Nanyang Technological University (ERI@N) and led by the BCA. The roadmap evaluated the potential electricity savings of six commercial building types (office, hotel, retail, hospitals, education and labour-intensive buildings) with the assumption that moderate technology advancements would be implemented, over a "business as usual" scenario. Net economic savings were computed based on additional costs required to install high-efficiency technology.

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95   New Climate Economy analysis based on data from Oxford Economics.

96   Based on an average cost of technical assistance of US$0.5–2 million per city. NCE estimates based on consultation with a range of city-focused institutions. It is important to note that many cities - particularly large cities in the OECD - are already investing voluntarily in developing city inventories, targets and plans. These plans are often more credible than those developed by a third party or consultant. It is therefore important that external assistance (i) builds on and enhances existing efforts by cities; and (ii) is focused on smaller cities and cities in the developing world which may have less recourse to domestic resources and have more pronounced skill gaps.

97   Based on the assumption that technical assistance for project preparation would represent 2.5–5% of total project costs after leveraged investments. NCE estimates based on consultation with a range of city-focused institutions.

98   Based on an average cost of technical assistance of US$750,000 per city, based on discussions with the World Bank. This is the estimate of the assistance required per city to improve creditworthiness, not necessarily to reach creditworthiness. It takes on average around 9 months to design and resource multi-year action-plans to lay the foundation for effective delivery of technical assistance.

APPENDIX: METHODS AND ASSUMPTIONS IN THE GLOBAL-LEVEL ANALYSIS

1. Introduction

This appendix presents the methodology used to estimate the additional costs and benefits of the urban action scenario developed by Erickson and Tempest (2014). This scenario assumes ambitious levels and rates of deployment for 11 mitigation measures within the building, transport and waste sectors in 99% of the world's urban areas by population. This covers an urban population of 3.9 billion in 2015, rising to 6.3 billion in 2050.

The baseline or "business as usual" scenario used by Erickson and Tempest (2014) draws heavily on the 4DS scenario presented in the International Energy Agency's *Energy Technology Perspectives 2014: Harnessing Electricity's Potential* (IEA, 2014a). The 4DS scenario, in turn follows the New Policies Scenario of the World Energy Outlook 2014 (IEA, 2014b). This scenario includes changes in energy use and emissions that may be expected to occur due to market forces and national policies that are currently proposed but have yet to be formally implemented, and it incorporates IEA forecasts for GDP and population growth. [1]

By comparison, the urban action scenario assumes a programme of ambitious climate mitigation at the city scale. The scenario predicts the potential economic and carbon savings that could be realised if measures in three sectors – buildings, transport, and waste – were deployed at an ambitious rate across the world's urban areas between 2016 and 2050. Estimates for the scope for and rate of deployment of the different measures included in this scenario are drawn from a variety of sources, particularly the IEA's 2DS scenario (IEA, 2014a). The 2DS scenario models the potential to reduce greenhouse gas (GHG) emissions to levels consistent with atmospheric CO_2 concentrations of 450ppm in 2100. In other words, this urban action scenario evaluates the potential for cities to achieve mitigation at a level compatible with the international goal to limit the average global long-term temperature rise to 2°C.

The analysis presented in this working paper expands upon the work of Erickson and Tempest (2014) by assessing the economic case for pursuing such a programme of mitigation in cities. In the following sections we describe our methodology, data sources, assumptions and the limitations of our approach.

2. Methodology

2.1 CALCULATION APPROACH

Estimating the economic case for the urban action scenario in Erickson and Tempest (2014) requires drawing data from a large number of sources and making various sector-specific assumptions. However, the general cost-benefit procedure is consistent across measures. First, the additional investment costs of the urban action scenario are calculated using data on the marginal or incremental cost of adopting a more energy-efficient or lower-carbon option instead of a conventional or "business as usual" option. The marginal cost of each unit is then multiplied by the number of units deployed in the urban action scenario relative to the baseline scenario. Second, the value of the energy savings associated with the deployment of all units is calculated by multiplying the energy savings generated in the urban action scenario relative to the baseline by forecast energy prices in the period from 2016 to 2050. Third, the additional investment costs and the cost-savings generated in the period to 2050 are compared to assess the overall economic case for each measure, each sector, and for the full implementation of the urban action scenario.

Three assumptions, which apply to all of the measures considered, have a particularly significant impact on the results: projections of future energy prices, choices of discount rates (which reflect the **opportunity costs faced by, and time preferences of, a prospective investor**) and estimates of technological learning (which dictate how quickly the costs of low-carbon technologies are expected to fall). This analysis tests the sensitivity of the results to these assumptions by considering a range of values:

- For energy prices, we generate results based on real annual energy price increases of 1%, 2.5% and 4%;[2]

- For discount rates, we generate results based on rates of 1.4%, 3%, and 5%;[3] and

- For technological learning rates, we calculate results based on both a standard and a high learning rate, with specific rates selected for each measure, as specified in Sections 2.2 and 2.3.

Costs and energy savings are estimated at a regional level (where data allows) using the regions considered by Erickson and Tempest (2014),[4] before they are aggregated in global estimates. Where available, current energy prices are obtained for each of these regions from the IEA's Energy Prices and Taxes Statistics (http://www.iea.org/statistics/topics/pricesandtaxes/).[5] Where regional energy price data are not available, country proxies are used to represent the wider region. 2015 US dollars are used throughout the analysis.

2.2 BUILDINGS: COMMERCIAL AND RESIDENTIAL

New Buildings and Retrofits

A consistent methodology is used to estimate the economic case for investing in more energy efficient buildings – both those to be retrofitted and those to be constructed – in the residential and commercial sectors. The calculation relies upon four datasets:

1. The additional installation costs per unit of floor area (US$/m^2) for retrofits and new buildings in the urban action scenario relative to the baseline;

2. Floor area installation rates (m^2/yr) for retrofits and new buildings;

3. Annual energy savings (kWh/yr) in the urban action scenario relative to the baseline; and

4. The specific composition of fuel use avoided (%).

The first of these datasets was obtained from an analysis completed for the Global Building Performance Network (GBPN) by Ürge-Vorsatz et al. (2015). Costs supplied by GBPN correspond to the regions used in this analysis and are disaggregated into 17 climate zones within each of these regions. Therefore, using the share of buildings in each climate zone in each region, these costs are aggregated into *regional costs per unit floor area* for both residential and commercial sectors, and in each case for both retrofits and new builds. The second and third datasets (for floor area installation rates and annual energy savings) are drawn directly from Erickson and Tempest (2014). As the floor installation rates are identical in the baseline and action scenarios, the additional costs of the urban action scenario can be attributed fully to the higher costs of efficient buildings rather than lower construction rates. The fourth dataset (on the specific composition of fuel savings) is drawn from the IEA's online statistics, and is based on the assumption that, within each region and sector, the composition of fuel savings is the same as the composition of total fuels consumed.[6]

Using these datasets, total additional costs are obtained by combining the installation costs with the installation rates. Energy cost savings are obtained by combining total annual energy savings with the energy price forecasts, taking into account the specific fuel composition.

Appliances and lighting

Estimating the economic case for investing in more energy efficient appliances and lighting relies upon three datasets:[7]

1. Cost to save a unit of electricity (US$/kWh) via the installation of high efficiency lighting or appliances;

2. Annual electricity savings (kWh/yr) from more efficient lighting and appliances; and

3. The split of these electricity savings between appliances and lighting (%).

The first of these datasets was obtained from the IEA (2014c). The cost estimates are based on the assumption that the energy savings in the urban action scenario are achieved via the installation of LED lighting and BAT (best available technology) appliances, relative to a baseline scenario with incandescent lighting in the residential sector, linear florescent lighting in the commercial sector,[8] and low efficiency appliances across both sectors. The second dataset was obtained directly from Erickson and Tempest (2014). The third dataset was obtained from the 2DS scenario of *Energy Technology Perspectives 2014* (IEA, 2014a),

which forecasts these splits out to 2050 at the level of the Organisation for Economic Co-operation and Development (OECD) and at the non-OECD level.

Using these datasets, annual electricity savings were split into savings from lighting, and savings from appliances.[9] These were multiplied by the cost to save a unit of electricity to determine the additional investment needs in the urban action scenario. Energy cost savings are obtained by combining total annual electricity savings with the electricity price forecasts.

Solar PV[10]

Estimating the costs and benefits of the additional solar capacity installed in the urban action scenario involved three datasets, each disaggregated by region:

1. Capacity factors (%);

2. Installation costs (US$/kW installed capacity) and annual running costs (US$/year/kW installed capacity); and

3. Annual electricity savings (kWh/yr) due to additional PV installations in the urban action scenario relative to the baseline.

The first and second of these datasets are sourced from the 450 Scenario of the *World Energy Outlook 2014* (IEA, 2014b). These are disaggregated by region and include price forecasts to 2030. The third dataset is obtained directly from Erickson and Tempest (2014).

Using capacity factors and average panel lifetimes, the installed capacity for each region is reverse-engineered from the annual electricity savings in the urban action scenario. The installed capacity is then used with the first dataset to estimate additional investment costs and running costs. Again, energy cost savings are determined by combining total annual electricity savings with the energy price forecasts.

2.3 TRANSPORT: PASSENGER TRANSPORT AND FREIGHT TRANSPORT

Urban planning and reduced travel demand

The incremental investment needs are not estimated for this measure. However, previous work for the New Climate Economy suggests that urban planning for compact and connected cities could reduce investment costs by US$3 trillion between 2015 and 2030 (Floater et al., 2014). The scale of potential savings is further supported by work from the World Bank, which finds that China could save up to US$1.4 trillion in infrastructure spending to 2030 if more compact urban forms were pursued (Zhang et al., 2013).

Energy savings are calculated using modal share data from Erickson and Tempest (2014) and regional energy intensity of transport data from the 2DS and 4DS scenarios in *Energy Technology Perspectives 2012: Pathways to a Clean Energy System* (IEA, 2012). These data are converted to fuel types using the regional specific data on energy use by fuel type from IEA statistics (https://www.iea.org/statistics/) on the assumption that fuel use by energy type is consistent in the urban action and baseline scenarios. Cost savings are then estimated using regional fuel price forecasts outlined above.

Mode shift and transit efficiency (passenger transport)

This cluster of measures is composed of three elements: mode shift, energy efficiency improvements for public transport vehicles, and electrification of the public transport fleet.

To calculate the investment requirements for the mode shift element, the following datasets are used:

1. The urban population by region;

2. Annual regional per capita travel distance (km);

3. Regional travel mode share (%);

4. Vehicle occupancy figures;

5. Vehicle-km per km infrastructure; and

6. Cost per km of infrastructure (millions 2015 US$).

Data on the person-km by transport mode and region in the baseline and urban action scenarios are obtained from Erickson and Tempest (2014). Total passenger-km for each transport mode are converted to vehicle-km using regional estimates of average vehicle occupancy. Vehicle-km by transport mode are converted to km of infrastructure using regional estimates of annual vehicle-km per km of infrastructure and estimates of the cost per km of infrastructure are used to calculate investment costs. These data are collected from Dulac (2014) and Replogle and Fulton (2014), and from consultation with experts (see Sections 2.2 and 2.3 for full details of data sources). In most cases, these data are only available at the OECD/non-OECD level.

To calculate the cost of energy efficiency improvements, three datasets are used:

1. Annual average travel distance by vehicle type (km);

2. Energy expenditure per km by transport mode; and

3. The cost per vehicle of energy efficiency improvements (US$/% improvement in efficiency).

Using the previously calculated total passenger-km by transport mode, the size of the transport fleet is estimated using regional estimates of annual average travel distance by vehicle type and vehicle occupancy. The change in the efficiency of the fleet is calculated by comparing the energy use per km in the baseline and urban action scenarios. It is assumed that the increase in efficiency of the fleet (over and above the baseline increase in efficiency) is the same as the increase in efficiency for each vehicle in the fleet. Data on the cost of transit efficiency improvements is drawn from the heavy-duty vehicle efficiency cost database in the *World Energy Investment Outlook 2014* (IEA, 2014c), and applied on a per vehicle basis. Only the portion of the fleet that is not part of the electrification scenario (below) is considered.

To calculate the cost of electrification, the size of the electrified fleet by region and transit mode type is calculated using the total size of the fleet (see above) and the IEA electrification scenario (IEA, 2014a). Estimates of the additional cost of these electrified vehicles, obtained from expert consultation, are then applied to obtain total investment costs.

Total energy savings are calculated using modal share data from Erickson and Tempest (2014) and regional energy intensity of transport data from the IEA 2DS and 4DS scenarios (IEA, 2012). These data are converted to fuel types using the regional specific data on energy use by fuel type from the IEA (2014a), again with the assumption that fuel use by energy type is consistent between the two scenarios. Cost savings are then estimated using the regional fuel price forecasts specified above.

Car efficiency and electrification

This cluster of measures comprises two elements: vehicle efficiency improvements and electrification of the transport fleet.

To calculate the cost of vehicle efficiency improvements, the following datasets are used:

1. The urban population by region;

2. Annual regional per capita travel distance (km);

3. Regional travel mode share (%);

4. Vehicle occupancy figures;

5. Average vehicle travel distance;

6. Energy expenditure per km; and

7. The cost per vehicle of energy efficiency improvements ($/% improvement in efficiency).

In order to calculate the size of the private vehicle fleet in each region, the person-km by region in Erickson and Tempest (2014) is multiplied by vehicle occupancy figures and average annual travel distance figures. The increase in the efficiency of the fleet is then calculated by comparing the energy use per km (by region) in the baseline and urban action scenarios. In line with the transit scenario, it is assumed the increase in fleet efficiency is the same as the per vehicle improvement in efficiency. The annual year-on-year improvement in efficiency (relative to the background improvements in the baseline scenario) is then used to calculate investment costs using the light duty vehicle efficiency cost database in the *World Energy Investment Outlook* (IEA, 2014c). Only the portion of the fleet that is not part of the electrification scenario (below) is considered.

To calculate the cost of electrification one additional data set is required, on the additional cost of electric vehicles.

The size of the electrified fleet is calculated using the total size of the fleet (see above) and the IEA electrification scenario (IEA, 2014a). The total cost is then calculated using data on the additional cost of electric vehicles compared with conventional light-duty vehicles, obtained from Mock and Yang (2014), the IEA (2014c) and expert consultation.

Total energy savings are calculated using modal share data from Erickson and Tempest (2014) and regional energy intensity of transport data from the IEA 2DS and 4DS scenarios (IEA, 2012). These data are then converted to fuel types using the regional specific data on energy use by fuel type from IEA statistics (https://www.iea.org/statistics/), with the assumption that fuel use by energy type is consistent in the baseline and urban action scenarios. Cost savings are then estimated using regional fuel price forecasts, as specified above.

Logistics improvements

No costs are estimated for this measure due to the large variability both of approaches and associated costs.

Total energy savings are calculated using modal share data from Erickson and Tempest (2014) and regional energy intensity of transport data from the IEA 2DS and 4DS scenarios (IEA, 2012). These data are then converted to fuel types using the regional specific data on energy use by fuel type from IEA statistics (https://www.iea.org/statistics/), with the assumption that fuel use by energy type is consistent between the baseline and urban action scenarios. Cost savings are then estimated using the regional fuel price forecasts specified above.

Vehicle efficiency and electrification (transport freight)

This cluster of measures is comprised of two elements: vehicle efficiency improvements and electrification of the transport fleet. To calculate the cost of vehicle efficiency improvements, the following data sets were required:

1. The regional urban population;

2. Tonne-km per capita by region;

3. Tonne per vehicle estimates;

4. Average annual freight travel distance by region;

5. Energy use per tonne-km under the baseline and mitigation scenarios; and

6. The cost per vehicle of energy efficiency improvements ($/% improvement in efficiency).

To calculate the size of the freight fleet in each region, the difference in tonne-km by region in the baseline and urban action scenarios developed by Erickson and Tempest (2014) is calculated. Vehicle tonnage estimates and average annual travel distance figures are then applied to produce an estimate of the freight fleet under the mitigation scenario. The increase in the efficiency of the fleet is then calculated by comparing the energy use by freight per km by region in the baseline and urban action scenarios. In line with the transit scenario, it is assumed that the increase in fleet efficiency is the same as the per vehicle improvement in efficiency. The annual year-on-year improvement in efficiency (relative to background improvements in the baseline scenario) is then used to calculate investment costs using the IEA (2014c) *World Energy Investment Outlook* heavy-duty vehicle efficiency cost database. Only the portion of the fleet that is not part of the electrification scenario (below) is considered.

To calculate the cost of electrification, the size of the electrified fleet is calculated using the total size of the fleet (see above) and the IEA electrification scenario (IEA, 2014a). The incremental cost of electrified freight (obtained from IEA, 2009; NRC, 2010; Taefi et al., 2013; Davis and Figliozzi, 2013; NRC, 2013; Taefi et al., 2014) is then applied to these figures to provide an estimate of investment needs.

Total energy savings are calculated using modal share data from Erickson and Tempest (2014) and regional energy intensity of transport data from the IEA 2DS and 4DS scenarios (IEA, 2012). These data are then converted to fuel types using the regional specific data on energy use by fuel type from IEA statistics (https://www.iea.org/statistics/), with the assumption that fuel use by energy type is consistent between the baseline and urban action scenarios. Cost savings are then estimated using the regional fuel price forecasts specified above.

2.4 WASTE

Recycling

No investment costs or energy savings were developed for this measure. However, research suggests that recycling in certain circumstances can generate net economic returns (Graedel 2011; Goe and Gaustad, 2014; Papargyropoulou et al., 2015).

Landfill gas

To calculate investment requirements in the waste sector, the following datasets are used:

1. Energy generation (kWh) from landfill gas by region;

2. Regional landfill gas capacity factors; and

3. Capital costs per MW of capacity and operating and maintenance costs per MW of capacity.

Estimates of energy generation from landfill gas are provided by Erickson and Tempest (2014). To convert this into facilities, electricity output is converted to generating capacity using regional data on capacity factors from World Energy Council and Bloomberg New Energy Finance (WEC and BNEF, 2013). Regional operating costs and capital costs from WEC and BNEF (2013) are then used to calculate total investment costs.

Data on energy savings from electricity generated are drawn from Erickson and Tempest (2014). These figures are converted into economic savings using regional electricity price forecasts.

3. Data sources and assumptions for each scenario

3.1 BASELINE SCENARIO

Table 1
Buildings

Activity Levels[11]	Residential urban floor space (m²) per capita are the same as national averages and will grow slowly (<0.5% per year) in OECD countries and faster (>1% per year) in developing countries.
	Commercial floor space is predominantly (>90%) in urban areas (Ürge-Vorsatz et al., 2012). Commercial floor space (m2) per capita will grow more quickly in developing countries.
	Per capita floor space and the associated growth rates are identical in the baseline and urban action scenarios.
Energy intensities	Both residential and commercial urban energy intensities (GJ or kWh per m² of floor space) will follow national averages within the OECD and in some developing countries. In other developing countries, these variables are adjusted by considering rural/urban splits of electricity access and traditional biomass use using data from IEA (2010).
	Globally, urban energy intensity will decline slowly for residential buildings (<1% per year), and remain nearly constant in commercial buildings as efficiency gains are offset by increasing demand.
Fuel types and GHG intensity of energy	Emission intensities for urban heating fuels and electricity (kg CO2-e per GJ or MWh) will follow national averages within the OECD and some developing countries. In the other developing countries, they are adjusted by considering rural/urban splits of electricity access and traditional biomass use using data from IEA (2010).
	Emission intensities of urban fuel use will decline gradually due to shifts away from coal and oil, while emission intensities of electricity will decline more rapidly due to recent national policies as in the IEA's New Policy Scenario projections up to 2035 (IEA, 2013) and later projections to 2050 from IEA (2012).
	The compositions of energy types (electricity, coal, natural gas, etc.) used in the commercial and residential sectors are obtained from http://www.iea.org/statistics.

Table 2
Transport

Activity levels[12]	Urban travel intensity (pkm per person) declines in cities in OECD countries, but grows by 1.5% or more per year until 2030 in developing countries. Mode share holds near constant in OECD countries but shifts to private vehicles in developing countries. Urban freight intensity (tkm per person) grows by 1–2% per year in OECD countries and by 2–6% per year in non-OECD countries.
Energy intensities	Urban passenger vehicle energy intensities (MJ/pkm) for private, bus, and train transport modes are the same as national averages. The energy intensity declines by 0.5–1% annually to 2050 for all modes except private cars in developing Asia, where it increases by 0.5–1.5% annually. Freight energy intensity (MJ/tkm) is the same as national average road freight intensities. These decline by 0.5–1% annually in OECD countries and many developing countries, but not in Russia, China or India.
Fuel types and GHG intensity of travel	Higher private electric vehicle ownership leads to a 3–4% decline in emission intensity by 2050 for passenger transport (depending on the intensity of the relevant grid). Urban fuels are predominantly gasoline, diesel or GHG-equivalent biofuels.

Table 3
Waste

Activity levels[13]	Waste generation in tonnes per capita holds constant in OECD countries through 2025, but grows by 1.5% per year in most developing countries. 2015 values for waste generation are drawn from Hoornweg and Bhada-Tata (2012). After 2025, waste generation in each region converges to a fixed global relationship with GDP in 2050 and waste collection converges to 2010 best practice (90%; IPCC, 2006). Waste composition remains constant (IPCC, 2006).
Energy intensities	Energy and GHG emissions as a function of waste stay constant, because waste composition remains constant (IPCC, 2006). Recycling and composting rates converge to current best practice in all regions by 2050 (Hoornweg and Bhada-Tata 2012).
GHG intensity	The share of methane captured from landfills grows by 3.1% per year in non-OECD countries and 1.0% per year in OECD countries. One-quarter of these facilities produce energy for the grid in all cases and all years. Carbon stored in landfills increases with rising waste generation and decreases with increased food composting. Avoided emissions exceed decreased sequestration. Collection rates, degradable organic content (DOC) and fraction of DOC that decomposes are constant (IPCC, 2006). Emissions avoided through recycling are modelled to represent a share of the emissions intensities of production for paper, steel, aluminium and plastics (t CO2e/t product; IEA, 2014). The percentage reduction in production emissions varies by product with a range from 50% (paper products) to 80% (steel and aluminium). As new product efficiencies improve over time, avoided emissions from new production decrease, based on IEA (2014).

3.2 URBAN ACTION SCENARIO

Table 4
Buildings

	Mitigation – assumptions and data[14]	Costs assumptions and data
New building heating efficiency	New buildings are constructed at passive levels, with heating requirements no less than 30 kWh/m² from 2020 to 2030 and 15 kWh/m² through to 2050 (Ürge-Vorsatz et al., 2012).	Additional construction costs per m² floor space – above those of the standard new buildings assumed in the baseline scenario – are obtained from Ürge-Vorsatz et al. (2015). These are disaggregated regionally and by building type (single-family, multi-family and commercial). Technological learning reduces real costs of passive, high-efficiency builds by 50% by 2050 (Ürge-Vorsatz et al. 2015); this is modelled by implementing a constant decrease in prices of 1.71% per year. Higher learning increases this rate such that the costs decrease by 60% by 2050, in line with the upper limit used by GBPN.
Heating retrofits	An aggressive building retrofit program begins in 2015, which upgrades 1.4%–3% of building stock per year such that all existing buildings are upgraded by 2040. This reduces their energy intensity by 30–40% compared with the baseline scenario and includes heat pumps in mid-latitude countries. This action scenario is guided by GBPN's analysis (Ürge-Vorsatz et al., 2012).	Costs per m² of floor space in the baseline and urban action scenarios are obtained from Ürge-Vorsatz et al. (2015). The additional costs of deep retrofits are used, rather than those of shallow, minimal retrofits. These costs are disaggregated regionally and by building type (single- family, multi-family and commercial). Technological learning for retrofits – and the consequent rate of price decreases – occurs at the same rate as for new builds.
Appliances and lighting	Aggressive deployment of efficient lighting and appliances takes place based on the IEA's 2DS scenario (IEA, 2014a).	Additional costs of high-efficiency appliances and lighting per unit of useful energy output ($/toe) – relative to the technologies adopted in the baseline scenario – are obtained from the *World Energy Investment Outlook* (IEA, 2014c). Regional variations in construction costs for efficient buildings from Ürge-Vorsatz et al. (2015) are taken as an index to estimate regional variations of costs for appliances and lighting. Splits of energy use between appliances and lighting are obtained from the IEA's 2DS scenario (IEA, 2014a) for both commercial and residential sectors and at both the OECD and non-OECD levels. Technological learning decreases real costs of high-efficiency appliances at a rate of 2.5% each year, which lies within the range of values reported in the literature (Desroches et al., 2013). This rises to 3.5% in the high learning scenario.
Solar PV	An increasing deployment of building-mounted solar PV is projected, based on the assumption that half of the solar PV in IEA's 2DS scenario (IEA, 2014a) is distributed PV, and that this is deployed in urban areas in proportion to the share of urban population in each region.	Investment costs and operation and maintenance costs per kW of installed capacity¬¬ – and average capacity factors – are obtained from the 450 Scenario of the *World Energy Outlook* (IEA, 2014b), which closely follows the 2DS scenario. Costs and capacity factors are disaggregated regionally and projected for 2012–2035 based upon the IEA forecasts, which account for technological learning and economies of scale. Beyond 2035, costs continue to change linearly at the same rates. Panel lifetimes are 20 years.

Table 5
Transport

	Mitigation – assumptions and data[15]	Costs – assumptions and data
Passenger transport: Urban planning and reduced travel demand	Land use planning for compact urban form reduces passenger travel activity (pkm per capita) up to 7% in OECD countries and 25% in developing countries. Reductions in road transport demand are based on the 2DS scenario in IEA (2014a) and are allocated by population to urban areas.	No costs are assumed for this measure. However, previous New Climate Economy work suggests that urban planning for compact and connected cities could reduce investment needs by US$3 trillion between 2015 and 2030 (Floater et al., 2014).
Passenger transport: Mode shift and transit efficiency	Expansion of public transport leads to 20% lower pkm mode share of light-duty vehicles (LDVs) and higher mode share for rail and bus transport.	Cost per km of infrastructure, operation and maintenance, occupancy estimates and annual vehicle travel distances, and annual vehicle travel distance per km of infrastructure were drawn from Dulac (2014), Replogle and Fulton (2014), and Schlömer (2014), and from consultation with experts. Most data are disaggregated only to the OECD and non-OECD level. The cost of transit efficiency improvements was drawn from the heavy-duty vehicle efficiency cost database in the *World Energy Investment Outlook 2014* (IEA, 2014c). The cost of electrified buses and trains for urban transport is collected from expert consultation and interviews with electric transport firms.
Passenger transport: Car efficiency and electrification	More efficient passenger transport, including more widespread deployment of electric vehicles, result in greater than 45% improvement in private vehicle efficiency globally. The energy intensity impact of electrification is based on the 2DS scenario variant Electrifying Transport (IEA, 2014a) for cars (light road), buses (heavy road), and rail beyond the share of energy from grid electricity reported in *Energy Technology Perspectives* (IEA 2012).	The cost of vehicle efficiency improvements was drawn from the light-duty vehicle efficiency cost database in the *World Energy Investment Outlook 2014* (IEA, 2014c). Annual vehicle travel distance is drawn from Schlömer et al. (2014). The incremental cost of electric vehicles was drawn from a review of academic literature (Mock and Yang, 2014; IEA, 2014c) and expert consultation. Based on a survey of literature, a conservative learning factor of 5% was applied to the incremental cost (Nemry et al., 2009, NRC, 2013; Kalhammer et al., 2007). This is increased to 7% in the high learning scenario.
Freight transport: Logistics improvements	Freight transport logistics improvements lead to a 5% reduction in tkm per capita by 2030 and 12% by 2035 (Façanha et al., 2012).	No costs are assumed for this measure. However, previous work for the New Climate Economy suggests that urban planning for compact and connected cities could reduce total public investment costs by $3 trillion between 2015 and 2030 (Floater et al., 2014).
Freight transport: Vehicle efficiency and electrification	Global freight energy efficiency improves 17% by 2030 and 26% by 2030. In addition, 27% of global freight is electrified by 2050, following the IEA's Electrifying Transport variant (IEA, 2014a).	The cost of vehicle efficiency improvements and vehicle tonnage estimates were drawn from the medium freight cost database in the *World Energy Investment Outlook 2014* (IEA, 2014c). Annual vehicle travel distance is drawn from the Eurostat database (http://ec.europa.eu/eurostat/data/database). The incremental cost of electrified freight is drawn from a survey of academic literature (IEA, 2009; NRC, 2010; Taefi et al., 2013; Davis and Figliozzi, 2013; NRC, 2013; Taefi et al., 2014). A learning factor of 5% is applied to the incremental cost of electrified freight for the period to 2050 in line with the value for electric vehicles. This value is increased to 7% under the high learning scenario.

Table 6
Waste

	Mitigation – assumptions and data[16]	Costs – assumptions and data
Recycling	Recycling rates rise to 80% of recoverable materials by 2050 in all regions by 2050.	No costs are assumed for this measure. However, previous New Climate Economy work suggests that urban planning for compact and connected cities could reduce investment needs by US$3 trillion between 2015 and 2030 (Floater et al., 2014).
Landfill gas capture	The fraction of methane captured rises 5.5% annually in non-OECD countries and 2.5% in OECD. This is a result of increased number and efficiency of capture facilities. OECD countries increase the share of facilities capturing methane to 80% by 2050, from 30% in the reference scenario. In non-OECD countries, the respective increase is 50% by 2050, from a reference case of 65%. The efficiency of capture increases 1.3% per year to 84% relative to a reference case of 0.3% growth in all countries. All regions experience 2% annual growth in methane capture capable facilities that also generate grid electricity.	The capital cost of capture facilities, operating costs and capacity factors were drawn from WEC and BNEF (2013). Based on the *Energy Investment Outlook* 2014 (IEA, 2014c) a learning factor of 5% is applied; the high learning factor is 7%.

4. Limitations

Long-term estimates of investment needs and economic costs carry a high level of uncertainty. This is due to, among other factors, the compound effect of assumptions and uncertainty surrounding emerging technologies, energy prices and economic growth over time. This work should therefore be seen as a high-level estimate of the investment needs and economic potential of an ambitious set of urban climate mitigation actions – but not as a business case for, or macroeconomic analysis of, large-scale low-carbon investment.

Due to limitations in the availability of data, the analysis in this paper frequently relies on low-resolution data disaggregated only to the OECD and non-OECD levels. These data are then applied to urban areas using variables such as urban population as a proportion of national population. This means that findings are applicable at a macro scale but not at the disaggregated city, national or regional levels. Caution should therefore be exercised in applying the specific results at less than a global scale.

It is also important to note that a number of factors were not considered in this analysis. Energy savings post-2050 are not included due to the high levels of uncertainty surrounding energy prices in the long term. Many avoided costs are not included in the economic analysis, particularly in the transport sector (i.e. cars not purchased and roads not constructed). Similarly, many potential benefits are not included in the assessment (for example, the health savings from improved urban mobility and reduced vehicle travel, or increased labour productivity in green buildings). Critically, feedback and rebound effects – changes in the consumption of energy due to changes in prices or due to increased income from energy savings – have not been accounted for in these models, although they may have significant effects on energy use and emissions over the period 2015–2050.

ENDNOTES - ANNEX

1 In IEA (2013), world GDP growth averages 3.4% per year over 2012–2040, while the population expands from 7 billion in 2012 to 9 billion in 2040, averaging 0.9% per year during the projection period.

2 Rates of energy price increases are highly uncertain. We consider three different rates (1%, 2.5% and 4%), which were guided by the range of projections in the *World Energy Outlook* (IEA, 2014b).

3 1.4% is consistent with the Stern Review (2007), 3%, is a standard real public discount rate in the developed world, and 5% would be an indicative real private discount rate.

4 United States, Other OECD Americas, OECD Europe, Japan, Other OECD Asia Oceania, Russia, Eastern Europe and Eurasia, Developing Asia, China, India, Middle East, Africa, Other Latin America, Brazil and Other.

5 Costs of various types of energy are required for the cost-savings calculations, including electricity, natural gas, coal, fuel oil, diesel and gasoline.

6 Data on compositions of fuel use in both the residential and commercial sectors – coal, oil products, natural gas, biomass, etc. – were obtained from the IEA's online statistics (http://www.iea.org/statistics/) for each region analysed.

7 Note that this economic analysis only considers the electricity-based appliances and lighting within the urban action scenario, due to lack of data describing investment costs of fuel-based technologies. Fuel-based technologies are significant but not dominant within this measure, accounting for around one third of energy savings.

8 These baseline lighting technologies are based upon *World Energy Outlook* surveys that estimate the most common lighting technologies current used in each sector, globally (IEA, 2014b).

9 Note that Erickson and Tempest (2014) include cooling technologies within the lighting and appliances measure, while the new build and retrofit costs from GBPN include costs of efficient cooling technologies. There is therefore a slight misalignment of their measures and our costs. However, cooling represents a relatively small portion of building energy use, and, furthermore, this misalignment cancels out when considering the aggregate costs of the building sector.

10 Note that Erickson and Tempest (2014) bundle fuel switching and solar PV into a single measure. This assessment only estimates the costs for solar PV due to a lack of availability of robust cost data for fuel switching.

11 Assumptions relating to activity levels, energy intensities and GHG intensities of energy are based upon Erickson and Tempest (2014).

12 Activity level, energy intensity and fuel type, GHG intensity assumptions are adapted from Erickson and Tempest (2014).

13 Activity level, energy intensity and fuel type, GHG intensity assumptions are adapted from Erickson and Tempest (2014).

14 Mitigation assumptions are adapted from Erickson and Tempest (2014).

15 Mitigation assumptions are adapted from Erickson and Tempest (2014).

16 Mitigation assumptions are adapted from Erickson and Tempest (2014).

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The Global Commission on the Economy and Climate, and its flagship project The New Climate Economy, were set up to help governments, businesses and society make better-informed decisions on how to achieve economic prosperity and development while also addressing climate change.

In September 2014, the Commission published Better Growth, Better Climate: The New Climate Economy Report. Since then, the project has released a series of country reports on the United States, China, India and Ethiopia, and sector reports on cities, land use, energy and finance. In July 2015, the Commission published Seizing the Global Opportunity: Partnerships for Better Growth and a Better Climate. It has disseminated its messages by engaging with heads of governments, finance ministers, business leaders and other key economic decision-makers in over 30 countries around the world.

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