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LETTER

Low carbon cities: is ambitious action affordable?

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Abstract Research has begun to uncover the extent that greenhouse gas emissions can be attributed to cities, as well as the scope for cities to contribute to emissions reduction. But assessments of the economics of urban climate mitigation are lacking, and are currently based on selective case studies or specific sectors. Further analysis is crucial to enable action at the urban level. Here we consider the investment needs associated with 11 clusters of low carbon measures that could be deployed across the world's urban areas in a way that is consistent with a broader 2°C target. Economic assessment of these low carbon measures finds that they could be deployed around the world with investments of c$1 trillion per year between 2015 and 2050 (equivalent to 1.3% of global GDP in 2014). When the direct savings that emerge from these measures due to avoided energy costs are considered, under the central scenario these investments have a net present value of c$16.6 trillion USD in the period to 2050. However, discount rates, energy prices and rates of technological learning are key to the economic feasibility of climate action, with the NPV of these measures ranging from -$1.1 trillion USD to $65.2 trillion USD under different conditions.

Keywords Cities · Climate Change · Mitigation · Economics · Finance · Investment

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1 Introduction

Urban areas cover less than 3% of the earth's surface, but they are home to more than half of the world's population and account for an estimated 67-76% of global energy consumption and 71-76% of global energy related CO_2 emissions (Seto et al. 2014). Avoiding dangerous levels of climate change is therefore contingent on ambitious levels and rates of mitigation within cities.

A clear understanding of the global contribution that city-scale action could make to the mitigation of climate change is now emerging. Recent work has developed single and multiple city emissions inventories (Ramaswami et al. 2008; Kennedy et al. 2011), assessed the factors that drive urban emissions (Dodman 2009) and analysed 'business as usual' emissions scenarios and low carbon urban development (Creutzig et al. 2015). However, a key issue that has yet to be fully addressed relates to our understanding of the economic case for climate action in cities. Faced with multiple and sometimes conflicting priorities, policymakers and other decision makers are often reluctant or unable to act without evidence of the economic feasibility of low carbon development. The presentation of an economic case is always a consideration in decision-making and is often a precondition for action.

Recent literature suggests that broad-based climate action can yield economic returns. For example the IEA (International Energy Agency 2015) finds that the new energy infrastructure needed to stay within 2 degrees could be paid for through the fuel savings that it would generate, and various city-scale case studies find a similarly strong economic case for some levels and forms of mitigation in cities (Gouldson et al., 2015a; b). Much of the literature, however, continues to portray climate change mitigation as a net cost rather than an investment. The IPCC Fifth Assessment, for example, finds that cutting emissions to shift to a 2 degrees pathway will cost 2-6% of global GDP in 2050 (IPCC 2014). Here we report the results of the first attempt to assess the economic case for urban mitigation at the global level by assessing both investment needs and the direct economic returns that these investments could generate.

2 Methods

Our analysis builds on a recent assessment of urban mitigation potential across 99% of the global urban population undertaken by Erickson and Tempest (2014a). This assessment - which is based on upon the UN 2014 World Urbanisation Prospects and covers 99% of urban agglomerations (UN 2014) - considers the deployment of 11 clusters of low carbon measures across the buildings, transport and waste sectors (see Table 1). These are sectors in which cities have the greatest scope for action; even though they are crucial to a low carbon transition, electricity supply and industry are excluded as they are often outside of the influence of city-level decision makers.

The emissions baseline for the Erickson and Tempest (2014b) analysis draws heavily on the International Energy Agency's (IEA) Energy Technology Perspectives 4DS scenario (Elzinga et al. 2014) and the New Policies Scenario of the World Energy Outlook 2013 (IEA 2013). It therefore takes into account changes in emissions and energy use anticipated by existing policies that are consistent with a 4-degree long-term increase in global average temperatures and a rise in the global urban population from 3.9 billion in 2015 to 6.3 billion in 2050. When measured against this baseline, the analysis suggests that adoption of the 11 clusters of low carbon measures across the world's cities could contribute over 10% of the total global emissions reductions needed to shift from a 4°C to a 2°C pathway by 2030 and over 15% in later years (UNEP 2014). It is important to note that these savings are largely additional to the reductions generated by existing policies or

Table 1 Clusters of measures

Buildings	
New building heating efficiency	New buildings are constructed at passive heating levels: ≈30 kWh/m^2 from 2020 to 2030 and 15 kWh/m^2 from 2031 to 2050.
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.
Appliances and lighting	Efficient lighting and appliances are aggressively deployed, based on the IEA's 2DS scenario.
Solar PV	Building-mounted solar PV are extensively deployed, based on the assumption that half of the solar PV in IEA's 2DS scenario (IEA 2014) 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) up to 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 delivery vehicles (LDVs) and higher mode share for rail and bus transport.
Passenger car efficiency and electrification	A combination of more efficient and electric private vehicles results in a > 45 % improvement in private vehicle efficiency globally. The energy intensity impact of electrification is based on the 2DS scenario variant Electrifying Transport and *Energy Technology Perspectives*.
Freight logistics improvements	Freight transport logistics improvements lead to a 5 % reduction in tkm per capita by 2030 and 12 % by 2035.
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.
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 2014b[xxi]

planned in the Intended Nationally Defined Contributions (INDCs) submitted before the 22nd Conference of Parties to the United Nations Framework Convention on Climate Change in Paris.

Given their potential contribution to carbon reduction, here we ask whether and under what conditions investments in the deployment of these measures across the world's cities might be affordable. To answer this question, we estimate the investment requirements and potential returns using the measure-based cost-benefit methodology developed by the Climate Smart Cities program at the University of Leeds (Gouldson et al. 2015a, b). Using this approach, the incremental costs of procuring, installing and operating low carbon measures are compared with costs of conventional options and behaviours under the baseline scenario. Costs and benefits are assessed and sensitivities evaluated under different conditions and assumptions. Space limitations prevent a full discussion of our methods and assumptions here, but full details can be found in the Supplementary Information (SI). Details of the calculation approach are set out in SI 2.1; the data sources and assumptions relating to the baseline scenario are presented in SI 2.2; details on the costs, benefits and deployment rates of measures in the urban action scenario are set out in SI 2.3; the parameter perturbations made for our sensitivity analysis are discussed in SI 3.2 and comparisons between our findings and those of other assessments are presented in SI 3.3.

3 Results and discussion

We present our results under different scenarios that are based on a sensitivity analysis that considers the influence of changes in three of the key variables that impact on low carbon investment - discount rates, energy prices and rates of technological learning (which dictate how fast the costs of efficient technologies are expected to fall as their production and use expands).

For the 'central' scenario, we apply a real discount rate of 3% and assume annual energy price increases of 2.5% and we reference learning rates that lead to technology costs falling by between 1.7% and 2.5% per year depending on the specific technology. Under these conditions, our findings indicate that the average global investment needs would be approximately $1 trillion per year between 2015 and 2050, which is equivalent to 1.3% of global GDP in 2014. We also find that these investments would lead to savings in energy expenditure of $1.6 trillion in 2030 and $5.9 trillion in 2050 in real terms (see Table 2). Across all investments, the average payback period weighted by investment value is 16 years and the net present value of the stream of costs and benefits associated with these investments between 2015 and 2050 is $16.6 trillion. We also note that these urban actions would continue to generate energy savings after 2050, and that they could generate substantial co-benefits relating to, for example, reduced air pollution and congestion and improved public health. However, the economic impacts of these co-benefits are not quantified in this analysis: the large, positive NPV reflects merely the direct financial savings from the bundle of low-carbon measures.

Under the 'central' scenario, we find that there is substantial variation in the economic case for low carbon investment in different sectors. For residential buildings, a strong economic case exists for new building heating efficiency measures, but not for retrofitting existing buildings. For commercial buildings, the case for investment in new buildings is stronger than that for retrofit, but at the global scale neither cluster of measures has a positive net present value under the central scenario. In the transport sector, there is a strong case for investment in vehicle efficiency and electrification measures, especially with rising energy prices, but measures to promote modal shift are less attractive. We stress though that these assessments are based only on direct savings aggregated at the global scale, and that the case for investments in measures such as public transport frequently could be stronger at the local level, particularly when improved mobility, air quality and other impacts are taken into account.

Our analysis also evaluates the sensitivity of low carbon investments to changing energy prices, discount rates and learning rates. Some investments – for example, more efficient residential buildings and vehicles – have a positive NPV even under scenarios where there are lower energy prices and higher discount rates. But others – particularly measures in commercial buildings and waste – only show positive returns on investment under scenarios with higher energy prices and lower discount rates. Across all cases it can be seen that the net

Table 2 The economic and climate impact of urban action scenario

Sector	Measure	Annual abatement 2050 (GtCO2-e)	Share of total abatement (%)	Total Investment[1] (2015–2050; USD trillions)	Energy cost savings[2] (2015; USD billions)		NPV[3](USD trillions)	Average Payback (years)
					2030	2050		
Buildings - residential	New building heating efficiency	1.2	15 %	5.3	267	957	2.1	8.4
	Heating retrofits	0.5	7 %	6.4	209	501	-0.3	20
	Appliances and lighting	0.9	11 %	0.1	147	529	3.7	0.2
	Fuel switching / solar PV	0.2	3 %	0.7	15.6	100	0.2	11
Buildings - commercial	New building heating efficiency	0.5	7 %	6.6	120	479	-2.1	21
	Heating retrofits	0.2	3 %	4	103	260	-0.7	23
	Appliances and lighting	0.7	8 %	0.4	96.2	584	3	1
	Fuel switching / solar PV	0.2	3 %	0.2	3.9	24.9	0	13
Sub-total buildings	4.5	57 %	23.7	961	3435	6	17.4	
Transport - passenger	Urban planning: reduced travel	0.5	6 %	-	101	553	2.9	-
	Mode shift and transit efficiency	1	12 %	6.9	210	676	1.4	16
	Car efficiency and electrification	0.9	11 %	2.5	198	777	3.8	4.9
Transport - freight	Logistics improvements	0.2	2 %	-	14.6	66	0.4	-
	Vehicle efficiency and electrification	0.3	4 %	1	94.4	348	2.2	4.5
Sub-total transport	2.8	35 %	10.4	618	2420	10.6	11.9	
Waste	Recycling	0.3	4 %	-	-	-	-	-
	Landfill gas	0.3	4 %	0.03	0.7	3	0	20
Sub-total waste	0.6	8 %	0	0.7	2.6	0	20	
Total	8	100 %	34.2	1579	5858	16.6	15.7	

[1] Undiscounted with reference learning factors

[2] Undiscounted with energy prices rising 2.5% annually from 2015

[3] 3% discount rate, energy prices rising 2.5% annually from 2015, reference learning factors

present value of investments in all three clusters of measures across all of the world's cities in the period to 2050 ranges from $-1.1 trillion USD to $65.2 trillion USD depending on the conditions for investment (please see SI 3.2 for further detail).

Given the significance of the sensitivities, we emphasise that these results provide only a high level and highly contingent estimate of the returns from low-carbon investment in urban areas. As highlighted in Fig. 1, the results vary considerably under different conditions. Furthermore, there are dynamics that are beyond the scope of this analysis which are likely to have significant long-term impacts on investment needs and returns. The development and widespread diffusion of autonomous vehicles, for example, could lead to major shifts in transport patterns that could in turn influence where people live and work and this could then go on to alter returns on investments in public transport. Our findings do not consider the potential for major disruptions of this kind or the wider influence that they could exert. These results are also not suitable for guiding individual investment decisions in specific regions. For example, while we find the retrofitting of commercial buildings to have a negative NPV when aggregated globally, such measures are likely to be highly cost-effective for older buildings in cold climates.

Notwithstanding the importance of these caveats, this global analysis of the economics of climate action at the city-scale provides a number of insights that are important for urban policymaking and for the urban climate change research agenda.

Firstly, ambitious urban climate actions can be seen as an investment opportunity rather than a cost. The investment needs are significant, and the payback periods are relatively long (at least for commercial investors), but with medium or high energy prices the investments would more than pay for themselves through the direct savings that they would generate. Carbon pricing or R&D support for low carbon technologies could make the economic case even more compelling.

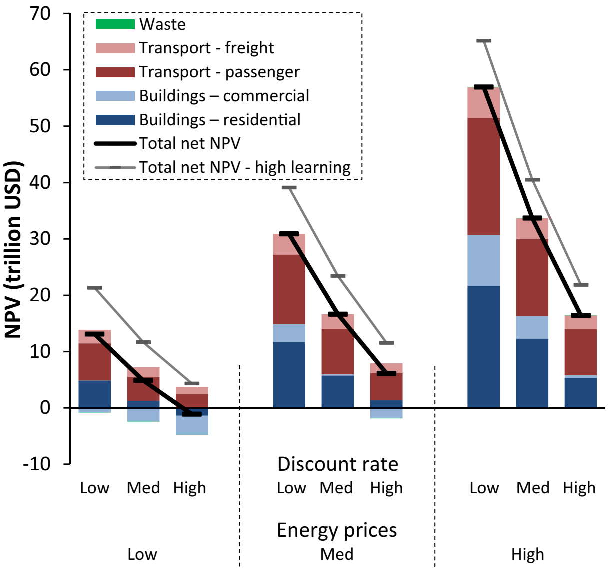

Fig. 1 The NPV of Urban Mitigation For Different Sectors Under Varying Conditions between 2015 and 2050. The net present value (NPV) of the urban mitigation scenario in the transport, buildings and waste sectors between 2015 and 2050. Under the 'low', 'medium' and 'high' scenarios, the real discount 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. These are conservative estimates that exclude significant economic savings from infrastructure not built and energy savings beyond 2050

Secondly, all of the measures could be more attractive if wider co-benefits were taken into account. Reduced air pollution, congestion and fuel poverty, and enhanced energy security and public health, are just some of the un-quantified benefits associated with these investments (Bain et al. 2015). A social case for investment that takes these co-benefits into account is likely to be much more attractive than a narrower private case that does not, and the presence of any positive externalities or spill-over effects creates a basis for public support.

Thirdly, if bundles of low carbon measures are adopted, there is scope for some of the savings from the more cost-effective measures to help pay for measures which show a less compelling case for investment. Coordinated action is needed to make the most of the opportunities. If profit motivated actors 'cherry-pick' the easier options then the prospects for tackling some of the more challenging measures via different forms of benefit capture and reinvestment will be reduced.

Fourthly, although low carbon development in cities could require significant investment, much of the finance could be secured through redirecting existing investment flows rather than searching for new ones. Recent estimates suggest that global infrastructure spending will rise from $2.7 trillion in 2013 to more than $8 trillion by 2025 (PWC 2014); (WEF 2013). Redirecting even a small proportion of this towards lower carbon options would have a significant effect on emissions. Innovative financing arrangements are also emerging to address any new financing needs, with energy performance contracting, green bonds, revolving funds and community ownership and tax abatement programs for climate friendly investment all showing promise (Junghans and Dorsch 2016); (Gouldson et al. 2015a, b).

Do these results mean that urban climate action in the world's cities is affordable? Certainly it is clear that, under favourable conditions, low carbon investments could more than pay for themselves in the medium to long term – even without factoring in potentially significant co-benefits. The presence of a compelling economic case suggests that the low carbon investment gap could be closed by redirecting existing flows of finance, adopting new policy frameworks to induce investment and encouraging innovative financing arrangements. Of course, the investment needs and the significance of other barriers to change could be formidable in the short term. However, we hope that economic analyses such as the one presented above can help to challenge perceptions that mitigation is necessarily costly, and to build a public, private and civic coalition committed to investing in more ambitious levels of climate action.

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