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The economics of climate mitigation: exploring the relative significance of the incentives for and barriers to low-carbon investment in urban areas

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Abstract

Achieving net zero emissions by 2050 – as envisioned in the Paris Agreement – will require radical changes to urban form and function. Securing the necessary commitments and resources will be easier in the presence of a compelling economic case for mitigation. Focusing on Recife in Brazil, we evaluate a wide range of low-carbon measures under different discount rates and energy prices. We find that under less favourable conditions (high discount rates; constant energy prices), the city could reduce its emissions by 15%, relative to business-as-usual trends, through investment which would generate returns at market interest rates. Under more favourable conditions (low discount rates; increasing energy prices), the city could reduce emissions by 25% with market-rate returns. That these opportunities have not been exploited indicates that barriers to low-carbon investment, including poor provision of information, transaction costs, and capacity deficits, may be of greater importance than the scale of direct incentives for raising climate investment. Decision-makers therefore need to prioritise dismantling these obstacles to low-carbon investment and fostering norms of environmental citizenship within cities.

1. Introduction

1.1 Cities as climate actors

In December 2015, the signatories to the Paris Agreement committed to keeping the global temperature rise this century to less than 2°C above pre-industrial levels. This has rightly been hailed as an extraordinary diplomatic achievement, negotiating seemingly irreconcilable differences to deliver "the first global accord on climate change with policy obligations for all countries" (Dimitrov, 2016: 1). Yet although negotiated and signed by national governments, delivering the Paris Agreement will depend substantially on action at the city scale.

Urban areas account for 71-76% of carbon dioxide emissions from global final energy use, and their share of emissions is likely to increase with rapid urbanisation (Seto et al., 2014). Achieving net zero emissions by 2050 – as envisioned in the Paris Agreement – will require radical changes to urban form and function. Mature cities will need to refurbish existing systems and infrastructures, and fast-growing cities will need to shift towards lower-carbon development pathways (Davis et al., 2010; Müller et al., 2013). Although the capacities and authorities of municipal authorities vary considerably, most have key powers that will be necessary for decarbonisation, including responsibility for zoning ordinances, building codes, urban transport projects and solid waste management (Romero-Lankao, 2007; Bassett and Shandas, 2010).

In addition to their importance as sites of climate action, cities have considerable political significance. While local-level decisions are partially shaped by their national and supranational contexts (Swilling et al., 2013), some city governments have shown remarkable leadership in the absence of external drivers of action, as demonstrated by the proliferation of climate change experiments and the growth of transnational networks of city governments (Anguelovski and Carmin, 2011; Castán Broto and Bulkeley, 2013). Indeed, a few cities pursued low-carbon urbanism as an explicit response to national government inaction, notably during the presidency of George W Bush (Bulkeley and Betsill, 2013).

Urban leadership may be needed more than ever. In parallel with rising optimism around the ambition of urban action actors, there is once again doubt about the capacity and will of national governments to act on climate change. Notably, the US (the world's second largest greenhouse gas emitter) has elected an avowed climate sceptic as President, China (the world's largest greenhouse gas emitter) has not yet established the policy frameworks needed to meets its Paris targets (Guan et al., 2016; den Elzen et al., 2016), and Brazil (the world's sixth largest greenhouse gas emitter) is struggling with recession and political scandal.

It is therefore imperative to engage, energise and empower city governments to mainstream mitigation into other urban development agendas. There are myriad reasons why cities might make climate commitments, but economic considerations are central for many decision-makers. Indeed, some authors suggest that the Paris Agreement was made possible by altered perceptions around the economic benefits of climate action (for example, see Wang and Li, 2015; Dimitrov, 2016). This paper therefore seeks to assess the economic case for climate action at the city scale. We adopt a bottom-up approach where we conduct benefit-cost analyses for a wide range of low-carbon measures in a case study city – Recife in Brazil. Our focus is on the near-term, local case for low-carbon investment, with the aim of providing insights relevant to prospective investors as well as policymakers.

This focus should not imply that economic perspectives alone should inform planning and policy. Indeed, large-scale low-carbon measures are typically motivated by so-called "co-benefits" rather than by opportunities for emissions reduction: mass transit is intended to improve road safety and air quality (Creutzig and He, 2009; Litman, 2014; Fuzzi et al., 2015), building retrofits are intended to reduce fuel poverty and energy bills (Castleton, 2010; Ürge-Vorsatz and Herrero, 2012), and so on. However, the financial feasibility of an investment is often a precursor to unlocking the necessary resources, and to that extent economic analysis can be seen as a necessary (if not a sufficient) basis to pursue less carbon-intensive forms of urban development.

Our methods and the case study are outlined in Section 2. We calculate the net present value (NPV) of nearly seventy mitigation options available to the city of Recife under a range of different discount rates, energy prices and carbon prices. This approach allows us to identify a large array of low-carbon measures, detailed in Section 3, that already promise commercial rates of return. In Section 4, we evaluate whether decision-makers should focus on improving the incentives for climate action, or prioritise dismantling barriers to investment in mitigation. Finally, in Section 5 we consider the pathways to deeper decarbonisation beyond the economically attractive mitigation potential. We start though by briefly reviewing key factors influencing low-carbon investment: the choice of discount rate and the presence of enabling policies.

1.2 The choice of discount rate

The choice of discount rate is central to evaluating the economic case for climate action, as it determines the rate at which future costs and benefits are converted into costs and benefits today. Since the impacts of climate change will unfold over many decades, decisions about how to act have intergenerational implications and carry a high level of uncertainty. Even in a hypothetical scenario where scientists have no uncertainty about the timing and scale of climate-related hazards, and economists can accurately cost the social, economic and environmental impacts of those events, the choice of discount rate could still lead to wildly different decisions about whether and how much to act on climate change.

The Ramsey approach (1928) proposes that a discount rate has two components. The first component considers the growth of the economy in the future, and the effect that growth would have on consumers' utility. Where growth is assumed to be higher, and to have a large impact on utility, the discount rate is higher. The second component is the pure rate of time preference:

the relative weight attached to a unit of income by individuals or generations over time, based on the assumption that people would prefer to receive a unit of income now rather than in the future. A time preference of 0 would suggest that costs and benefits borne in the future are valued equally to those borne in the present.

While the principles underpinning the discount rate are well-understood, debate continues over the appropriate parameters in different contexts. The implications of the choice of discount rate are significant. In The Stern Review on the Economics of Climate Change, Stern (2006) used a relatively low discount rate of 1.4% per year, therefore placing a high value on future costs and benefits. The results of his analysis led Stern to call for aggressive and immediate investment in emissions reduction, arguing that the costs of mitigation in the short term are likely to be much less than the costs of climate change impacts in the longer term. By comparison, Nordhaus (2007) argued that the variables adopted in a benefit-cost analysis should be based on observed behaviour, reflected in market interest rates, rather than a normative claim about how we ought to value the future. Accordingly, he proposed an equilibrium real discount rate of 5.5% per year.[1] Nordhaus concluded that the optimal abatement strategy is to maintain investment in conventional capital in the near future, thereby generating additional resources for investment in mitigation and adaptation in the longer-term.

The different treatment of opportunity costs and social time preferences by these academics catalysed extensive research into selecting and/or reconciling discount rates (see Arrow et al., 2013; Moxnes, 2014; Heal and Millner, 2014). Yet there have been few assessments of the way that the choice of discount rate may influence the economic feasibility of mitigation for prospective investors, and none that evaluate the aggregate impacts at the city scale. This study is intended to redress this gap.

1.3 Improving the economic case for climate mitigation

Although there is scope for governments to act on climate change, to a large extent global investment in mitigation will be the sum of local, private decisions by households, businesses and local governments. In the absence of a compelling economic case for mitigation, governments can pursue two alternative strategies to drive action: improving the incentives for, or overcoming the barriers to, low-carbon investment.

Carbon pricing is a standard economic prescription to incentivise emissions reduction. This policy is intended to internalise the social costs of pollution, so that an environmental externality is better reflected in the prices that shape private decisions. Carbon pricing is intended to make sure that prospective polluters bear the cost of emissions, so that they more likely to choose low-carbon options over fossil fuel-based goods and services. A price on carbon can be achieved by establishing a tax on greenhouse gas emissions or through an emissions trading scheme, although Stern (2006) observes that regulation can also place an implicit price on carbon. The economic literature largely agrees that carbon pricing is the most efficient and cost-effective way to achieve emission reductions (for example, see Goulder and Parry, 2008; Aldy and Stavins, 2012; Jenkins, 2014). However, extensive debate continues about the social cost of carbon that should ideally guide carbon pricing (see for example, Guo et al., 2006; Hope, 2008; Grubb, 2014; van den Bergh and Botzen, 2015). This is at least

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[1] In economic terms, the first component of a discount rate is a function of the economic growth rate and the consumption elasticity of marginal utility (how much wellbeing changes in proportion to changes in levels of consumption). The higher the expected growth rate and the larger the elasticity of consumption, the more our future welfare is assumed to increase and – accordingly – the higher the discount rate. Stern assumed a real increase in per capita output of 1.3% per year, a consumption elasticity of 1 and a time preference of 0.1% per year. In other words, he projects an annual increase in global GDP of 1.3%, that any changes in consumption will be exactly proportionate to changes in wealth and that a unit of income received in one year will be valued at 99.9% of its present value the following year. By comparison, Nordhaus assumed a consumption elasticity of 2 and a time preference of 1.5% per year.

partially because the current value of future monetary damages depend on the discount rate used and the mitigation policies put in place over coming decades (Howarth et al., 2014; Pizer et al., 2014). Despite these uncertainties, carbon pricing and emission trading schemes exist in a growing number of jurisdictions, including the European Union, South Korea, New Zealand, some states in the USA and Canada and some cities in China and Japan.

Where the financial incentives for climate action are sufficient to mobilise private low-carbon investment, governments need to identify and tackle various barriers to change. Relevant literature argues that investment decisions will be influenced by a mix of motivations, such as personal commitment, social norms, embedded behaviours, institutional inertia, risk averseness and capacity deficits (see Semenza et al, 2010; Gifford et al. 2011; Harries and Penning-Rowsell, 2011; Hussein et al. 2011; Simalenga, 2011; Berkhout, 2012; Rickards et al. 2014). Much of the literature on this topic presumes that these barriers to low-carbon investment will be overcome if the risk-adjusted returns are high enough. We test this assumption by examining the unexploited scope for economically attractive mitigation measures at the local level. We hope that our findings will shed light on the relative importance of incentives for and barriers to low-carbon investment and behavioural change.

2. Case Study and Methods

To explore the relative importance of these different factors, this paper adopts the city of Recife in northeast Brazil as a case study. The analysis is based on a bottom-up assessment of the investment needs, returns and mitigation potential of a wide range of low-carbon measures. This approach has been developed explicitly to contrast with global, top-down assessments on the economics of climate change. We test the economic case for climate action with four different discount rates and three different rates of energy price increase. For each combination of discount rates and energy prices, we identify a package of economically attractive low-carbon measures and assess the NPV of that package. We also calculate the impacts of this package of measures on the city's carbon emissions over the next fifteen years, compared 'business as usual' modes of development. The findings are drawn together to determine the economic case for low-carbon investment in Recife under different scenarios.

2.1 Case study: Recife, Brazil

Brazil is the largest country in Latin America, and its population of over 200 million people makes it the fifth most populous country in the world (World Bank, 2017a). In the decade to 2014, Brazil's economy grew on average by 3.3% per year, making it the seventh largest economy in the world (IEA, 2016). Its rapid economic growth was accompanied by dramatically increasing energy demand. Brazil is the eighth largest energy consumer and the tenth largest energy producer in the world. The sector with greatest demand for energy in Brazil is industry, followed by the residential and commercial sectors. Energy supply comes primarily from oil and other liquid fuels (47%), hydroelectricity (35%) and natural gas (8%) (EIA, 2014). More recently, the Brazilian economy has been shrinking at a rate of 0.5% per year, while national investment by the oil industry has been slashed due to falling revenues, high debt and the repercussions of the Petrobras corruption scandal (IEA, 2016).

Economic development, population growth and rising demand for food and energy have created environmental challenges, as well as unevenly distributed social and economic gains. Excluding land use change and forestry, Brazil was ranked as the seventh largest GHG emitter in 2013 (WRI, CAIT, 2017). This underscores the importance of tackling emissions from households, industry, transport, waste and other sectors that are predominately concentrated in urban centres. While subnational bodies are critical to implementation, however, the National Plan on Climate Change (2008) and National Policy on Climate Change (2009) remain the main bodies responsible for setting climate targets and designing climate policies (Ludeña and Netto, 2011).

Even by the standards of Latin America, local actors in Brazil have substantial autonomy in designing and implementing local development strategies. This has fuelled fiscal and administrative strengthening of municipal authorities (Bossuyt, 2013). As of 2015, 86% of Brazilians lived in cities (World Bank, 2017b). Although Sao Paolo and Rio de Janeiro are easily the country's largest cities, with populations of 11 million and 6.5 million respectively, the fate of most urban dwellers in Brazil will depend upon the quality of development in second-tier cities, which are home to 53.2% of Brazil's urban population (IBGE, 2014). Of these second-tier cities, Recife was chosen as a case study in response to enthusiasm for the proposed method and outputs from the City of Recife.

With a population of 1.6 million people (IBGE, 2014), Recife is the capital of the state of Pernambuco and the largest city in the Northeast region. It has a tropical climate, with average daily temperatures ranging from 26°C to 29°C and average humidity above 70% all year round (Recife.com, 2015). Recife had a GDP per capita of R$29,037 (US$13,482) in 2013 (IGBE, 2013). However, the city's high middle-income status hides substantial economic inequality. 12% of the population are not served by the municipal water system, 57% are not served by the municipal wastewater drainage system and 23% live in informal settlements (ICLEI, 2015). In 2012, people living within the city produced an average of 2.03tCO_2-e (ICLEI, 2014), compared to a per capita average of 12.47tCO_2-e in OECD countries (OECD, 2015). However, like most other cities (Satterthwaite, 2008), there are significant inequalities in per capita energy consumption and emissions production within the city.

The small carbon footprint of Recife is partially because of the low carbon intensity of the electricity supplied to the city and partially a legacy of ambitious energy conservation measures implemented across Brazil in the early 2000s. Emissions in the city are primarily produced by the transport sector (65.6%), followed by waste (19.3%), residential buildings (6.4%), industry (4.9%) and the commercial and public sectors (4.2%) (ICLEI, 2014). In order to continue on its low-carbon development trajectory, the City of Recife is implementing the project Promoting Urban Low Emission Development Strategies in Emerging Economies (UrbanLEDS), with technical assistance from ICLEI and support from UN-Habitat.

2.2 Baseline analysis

Our baseline scenario presents levels of energy use, energy expenditure and GHG emissions in Recife since 2000, and projects how these will change to 2030 based on business as usual trends and planned investments. The baseline was largely developed from the city-scale emissions inventory prepared for 2012 (ICLEI, 2014) which aligns with the Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC).

The emissions inventory provided details on energy consumption by fuel type in Recife in 2012. In order to calculate levels of energy consumption between 2000 and 2012, we used data on the changing rates of energy consumption from the Energy Research Company (EPE, 2009; 2011; 2013a; 2013b), ICLEI (2014), and Hornweg and Bhada-Tata (2012). Levels and composition of energy use in the commercial, domestic, industrial, transport and waste sectors were forecast to 2030 based on a continuation of trends between 2010 and 2014. This method captured recent business as usual trends in, for example, population growth, economic growth, background improvements in energy efficiency and changing consumer behaviour.

Trends in GHG emissions and energy expenditure were calculated from the projected changes in the levels and composition of energy use. We model three alternative scenarios for energy expenditure over this period, based on a 0%, 2% and 4% annual increase in real energy prices. Projections of the changing carbon intensity of electricity were informed by World Bank estimates of generation capacity in Brazil through to 2030 (Yepez-García et al., 2010; Tolmasquim, 2012). The resulting baselines predict energy consumption, energy bills and carbon footprints through to 2030 under business as usual conditions. The data sources, methods and assumptions are detailed in Appendix A.

All future activities are compared against these baselines. In practice, Recife might not be able to sustain its current development trajectory due to, for example, traffic congestion from the increasing number of private motor vehicles. The recent economic crisis in Brazil has also affected growth rates. However, the purpose of these baselines is to provide a business as usual scenario against which to measure the potential impacts of the low-carbon measures.

2.3 Identification and economic assessment of measures

A short list of low-carbon measures was prepared through a literature review and stakeholder consultations. The participants in the stakeholder workshops are listed in Appendix B. The resulting short list is not intended to be exhaustive. In particular, given the focus on the economic valuation of low-carbon measures, this analysis does not consider the impact of significant changes in land use planning or the spatial distribution of activities within Recife. Such modifications to urban form and function are important, but outside the scope of this study.

The performance of each measure was assessed using data from academic and grey literature, which was refined through stakeholder review. Our evaluation involved a benefit-cost analysis of each measure based on the direct, private economic costs and returns from deploying that measure. The costs incorporated the capital, running and maintenance costs of each measure, focusing on the marginal or extra costs of adopting a more energy efficient or lower-carbon alternative. The benefits incorporated the economic savings from reduced energy expenditure over the lifetime of the measure, taking into account installation and performance gaps. Inputs, data sources and assumptions for each measure are detailed in Appendix A. A measure was considered to be economically attractive on commercial terms if it generated a positive NPV over its lifetime at the selected discount rate. By focusing on the abatement potential of readily available technologies over the next fifteen years, using current prices and efficiencies rather than assuming technological learning, we implicitly assess the need for technology policy to achieve abatement goals.

We assessed the importance of the choice of discount rate to prospective investors by conducting the benefit-cost analysis for each measure under four different real discount rates: 1.4% as the average from The Stern Review (Stern, 2006), 3.5% as a mid-level discount rate, 5.5% as the rate used by Nordhaus (2007) in his critique of the Stern Review and 7.5% as a plausible discount rate for private investors seeking to maximise their returns. For reference, the Central Bank of Brazil has a nominal discount rate of 13.75%, which – with an inflation rate of 6.3% per annum in 2014 (World Bank, 2015) – equates to a real discount rate of 7.45%. We further tested the feasibility of each measure under different energy price scenarios, calculating the NPV of all measures over their lifespan with 2014 energy prices and with an annual increase in real prices of 2% and 4%.

2.4 Aggregation of findings

Rates of deployment were selected based on levels of uptake deemed realistically achievable by the stakeholder panels. The mitigation potential of each measure at this rate of deployment was based on calculations of the renewable energy generated, energy use avoided or waste emissions prevented, compared with BAU levels, in the period to 2030. As each measure could be in place for many years, the models incorporated the changing carbon intensity of electricity consumption. None of the scenarios considered any level of technological learning, so our assessments of the measures are conservative estimates of both the economic case and mitigation potential to 2030.

These estimates of mitigation potential underpinned our calculations of the impact of a carbon price on the NPV of each measure. We evaluated the impact of a carbon price of US$10/t$CO_2$-e and US$25/tCO_2-e on the economic feasibility of each measure. This was achieved by multiplying the total emission reductions delivered by a measure each year by the selected carbon price. Importantly, when calculating the NPV of a measure and assuming that the policy remains constant in 2015 USD terms to 2030, a carbon price of US$10 per tonne of carbon dioxide equivalent would be valued at $8.09 in 2030 with a discount rate of 1.4%, and at $3.11 with a discount rate of 7.5%. A carbon price of US$25 per tonne of carbon dioxide equivalent would be valued at US$20.23 in 2030 with a discount rate of 1.4%, and at $7.76 with a discount rate of 7.5%.

The results from the assessment of the performance of each measure, and the scope for deploying each measure, were aggregated to determine the potential impact across the different sectors and for the whole city. This underpinned calculations of overall investment needs and paybacks in each scenario, as well as impacts on greenhouse gas emissions in the different sectors in the city.

Many low-carbon measures interact with each other, so their performance depends on whether/to what extent another option is also adopted (Bajželj et al., 2013). This has long been a challenge in appraising different mitigation options (Kesicki and Ekins, 2012; Vogt-Schilb and Hallegatte, 2014). For example, the economic and carbon savings from converting taxis to compressed natural gas (CNG) depend on the extent of modal shift to the expanded bicycle scheme or Bus Rapid Transport (BRT) system. Similarly, the benefits of turning off the lights for an extra hour per day depend on whether the lights are compact fluorescent (CFL) bulbs or light emitting diodes (LEDs). When determining the potential economic and carbon savings across the city, we included the effect of each measure on the mitigation potential of other measures in order to develop realistic assessment of their combined impacts.

3. Results

3.1 Business-as-usual trends in urban energy use, energy expenditure and emissions

Under business as usual conditions, we predict that total energy consumption in Recife will increase by 91% between 2014 and 2030. Factoring in slight improvements in the carbon intensity of energy consumption, this will lead to an increase of 79% in production-based GHG emissions from Recife over the same period. With forecast population increases, this equates to an increase of 58% in per capita emissions. The rise in energy use and emissions will overwhelmingly come from the transport sector (Figure 1), partially due to the growing share of trips completed by private motor vehicles and partially because the low emissions factor of Brazilian electricity means that other sectors will remain relatively carbon-efficient.

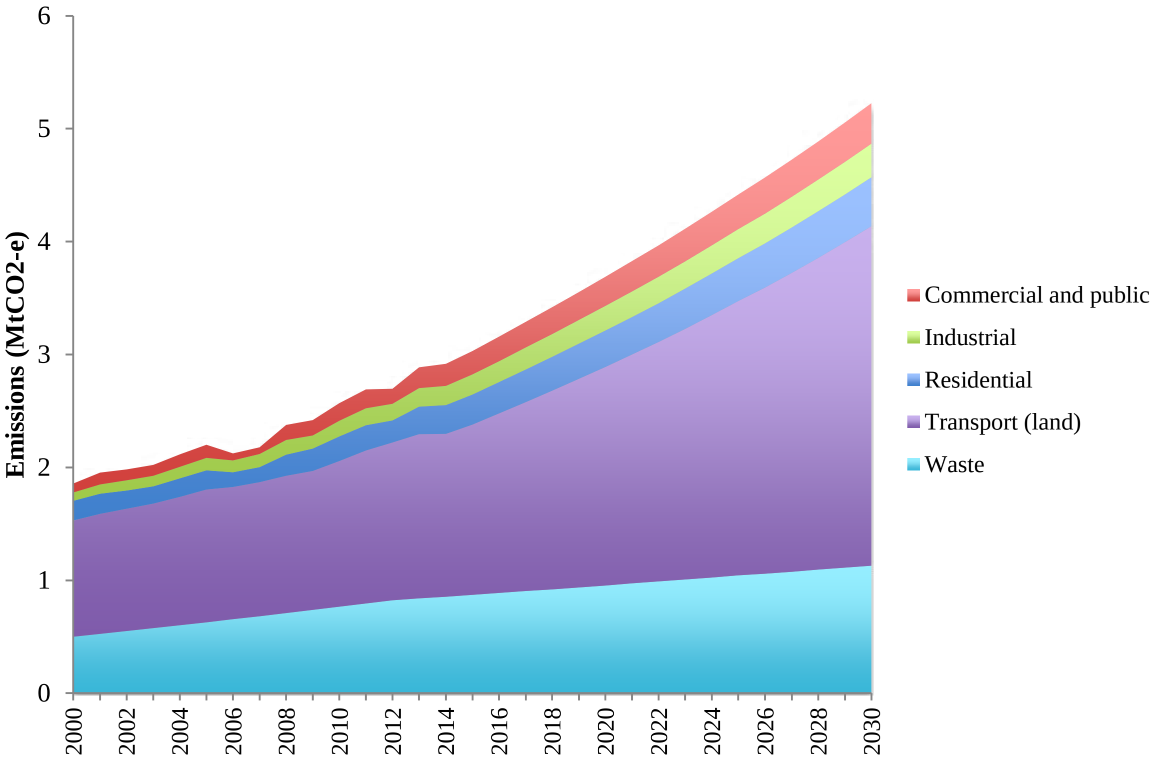

Figure 1. Production-based GHG emissions from the city of Recife between 2000 and 2030.

3.2 The economic case for urban climate mitigation

We find that a wide range of low-carbon measures could be deployed in different sectors in Recife. However, we also find that the economic case for investment in these options is subject to the choice of discount rate, expectations about future energy prices (Figure 2) and the introduction of a price on carbon (Figure 3).

Our most conservative scenario assumes that energy prices will remain constant, that prospective investors will use a discount rate of 7.5% and that there will be no price on carbon. Even under these conditions, our analysis indicates that many low-carbon measures will prove to be economically attractive compared to higher-carbon alternatives. These include no-cost behavioural changes such as turning off lights, investments with low capital costs such as increasing building albedo and measures that immediately offer high rates of return, such as more efficient air conditioners. In this scenario, the bundle of economically attractive measures has a NPV of US$1.4 billion. On these grounds, there seems to be an opportunity to mobilise levels of low-carbon investment that are significant when compared to Recife's annual GDP of US$16.6 billion in 2014 or its annual energy bill of US$1.5 billion.

We find that the economic case becomes even more compelling if we assume that energy prices will increase in real terms and/or that prospective investors will use a lower discount rate. Measures that achieve a positive NPV under these conditions include rooftop solar panels, ambitious LED targets and energy-from-waste infrastructure with combined heat and power. With an annual increase in real energy prices of 4% (which seems unlikely considering recent trends in global oil and gas markets), the bundle of economically attractive measures has a NPV of US$3.0 billion – even with a discount rate of 7.5%. With a discount rate of 1.4% per annum and energy prices at 2014 levels, the bundle of economically attractive measures has a NPV of US$3.1 billion. Under the most favourable conditions for low-carbon investment, with high increases in real energy prices and a low discount rate, we identify a bundle of low-carbon measures in Recife with a NPV of US$8.3 billion (Figure 2). The most attractive options in each scenario are presented in Table 1.

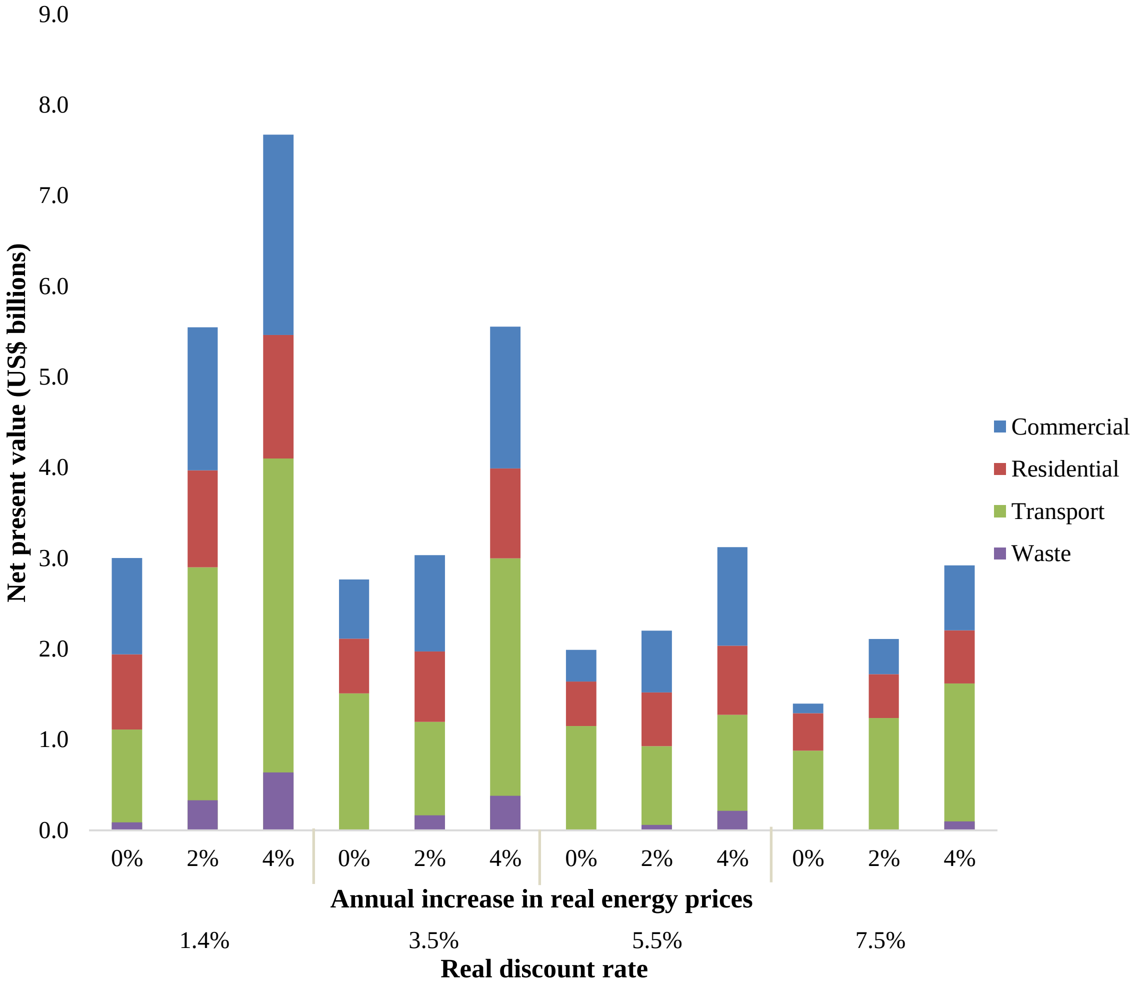

Figure 2. Net present value of the cost-effective low-carbon measures available in Recife with four different discount rates and under three different energy price scenarios.

Table 1. The net present value (USD millions) of the two most economically attractive low-carbon options in each sector under each of the twelve different scenarios.

		ANNUAL INCREASE IN REAL ENERGY PRICES											
		0%				2%				4%			
		DISCOUNT RATE:				DISCOUNT RATE:				DISCOUNT RATE:			
Sector	**Measure**	**1.40%**	**3.50%**	**5.50%**	**7.5%**	**1.40%**	**3.50%**	**5.50%**	**7.5%**	**1.40%**	**3.50%**	**5.50%**	**7.5%**
Commercial	Air conditioner - 20% improvement on BAU efficiency	$791	$465	$222	$31	$1,218	$806	$501	$261	$1,739	$1,221	$838	$537
	Setting LED target of 100% by 2030 (commercial buildings)	$112	$69	$37	$12	$167	$114	$75	$43	$234	$169	$119	$80
Residential	Refrigerator – 20% improvement on BAU efficiency	$224	$193	$169	$149	$260	$222	$194	$170	$304	$258	$223	$195
	Energy management - appliances	$174	$146	$125	$107	$209	$173	$147	$126	$251	$207	$174	$148
Transport	EU carbon emissions vehicle standards	$1,203	$903	$687	$523	$1,727	$1,307	$1,006	$776	$2,374	$1,805	$1,397	$1,086
	Increase in bus service (40%) hybrid	$477	$331	$226	$145	$155	$76	$20	-$23	-$235	-$231	-$227	-$224
Waste	Energy from waste (combined heat and power)	$83	-$10	-$70	-$112	$325	$160	$54	-$20	$631	$373	$208	$93
	Waste collection – hybrid retrofit	$5	$4	$3	$2	$6	$5	$4	$3	$8	$6	$5	$4

Not surprisingly, we find that the introduction of a carbon price would have a positive impact on the economic case for mitigation. With a discount rate of 1.4%, a carbon price of US$25/tCO$_2$-e would increase the NPV of the bundle of cost-effective measures from US$4.0 to US$4.2 billion. With a discount rate of 7.5%, a carbon price of US$25/tCO$_2$-e would increase the NPV of this bundle of measures from US$1.3 billion to US$1.4 billion. However, it is apparent from comparing Figures 2 and 3 that an annual energy price increase of 2% would have a much more significant impact on the economic case for low-carbon investment than a fixed carbon price of US$25.

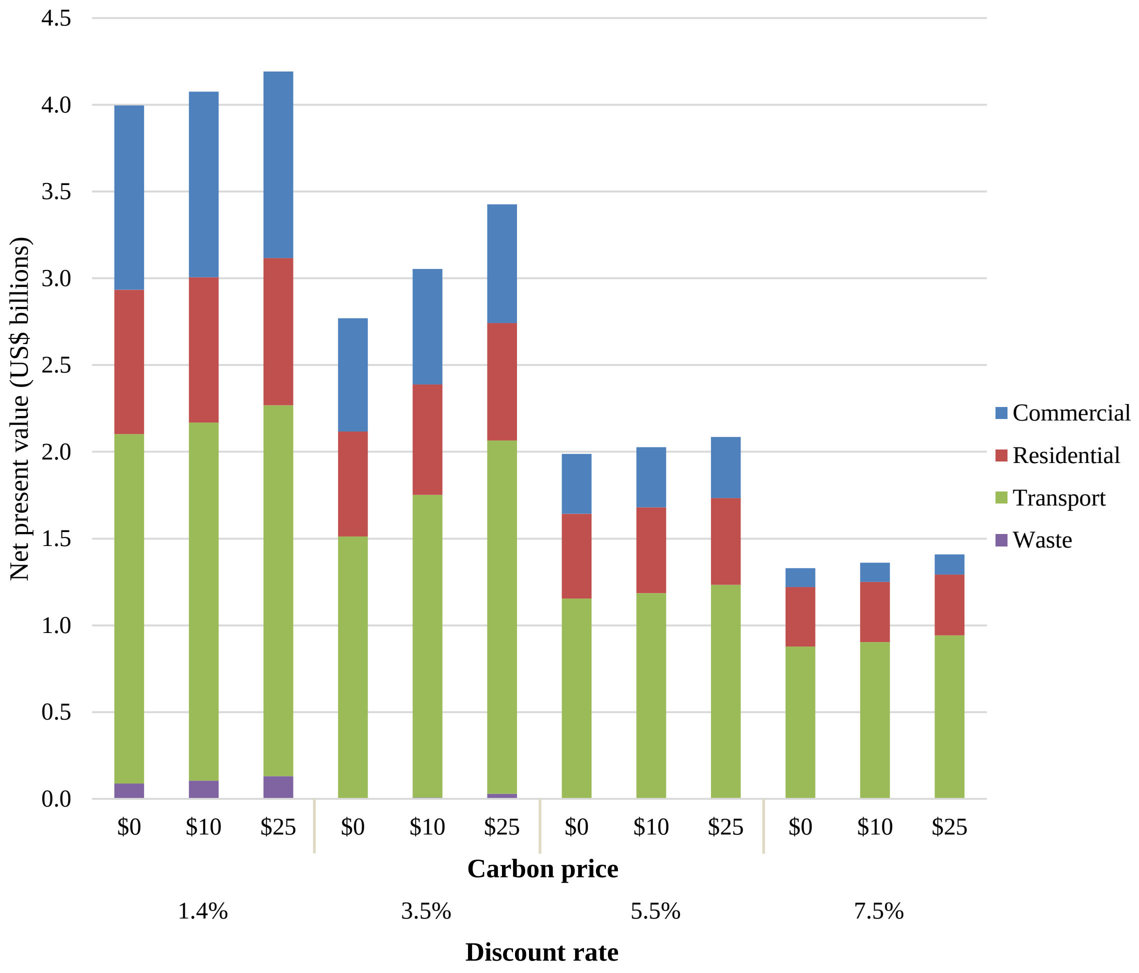

Figure 3. Net present value of the cost-effective low-carbon measures available in Recife with four different discount rates and under three different carbon price scenarios.

3.3 The mitigation potential of economically attractive climate actions

Ultimately, the success of a climate mitigation strategy should be largely measured by the emission reductions that it delivers. Each of the scenarios presented in Figures 2 and 3 yields different levels of carbon savings, depending on the particular measures that are economically feasible with that specific combination of discount rates, energy price increases and carbon prices.

We should note that, in our models, each measure has the same rate of deployment in all scenarios. In other words, if a measure is included in a scenario (because it has a positive NPV under that scenario's parameters), we assume the same level of adoption and consequently the same level of carbon savings. In practice, higher returns due to rising energy prices or lower interest rates might increase demand for low-carbon measures. Alternatively or additionally, the income from these investments may be spent on goods and services that increase energy consumption (van den Bergh, 2011; Gillingham et al., 2015). In the absence of reliable data about elasticity of demand and the scale of rebound effects, we used the rate of deployment recommended by the stakeholder panel across all scenarios.

Under the least favourable conditions for low-carbon investment and behavioural change, the city could reduce emissions by 15% relative to business as usual trends. Under the most favourable conditions, the city could reduce emissions by 25%, relative to business as usual trends (Figure 4). The other scenarios all offer emission reductions within this range. It should be emphasised that these carbon savings would be obtained just by exploiting the economically attractive mitigation options in each scenario.

Details of the most carbon-effective options available to the city of Recife are detailed in Table 2.

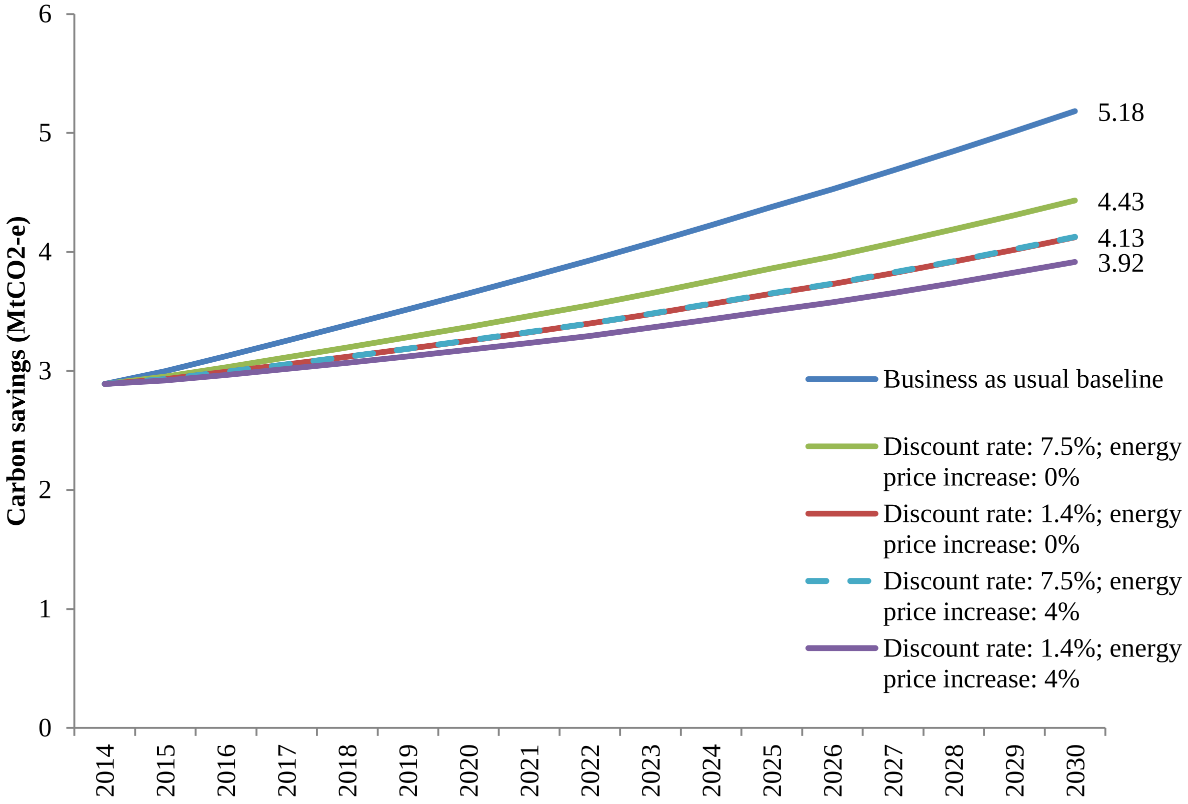

Figure 4. Emissions from Recife between 2000 and 2030 under five different investment scenarios.

Table 2. The most carbon-effective measures available in each sector in Recife.

Sector	**Most carbon-effective measures available to Recife**		**Most carbon-effective measures available to Recife that also generate a market return***	
	Measure	Carbon savings (ktCO2-e)	Measure	Carbon savings (ktCO2-e)
Commercial	Air conditioner - 20% improvement on BAU efficiency	394	Air conditioner - 20% improvement on BAU efficiency	394
	Setting light-emitting diode (LED) target of 100% by 2030	109	Setting LED target of 100% by 2030	109
Residential	Solar photovoltaic panels - 10% of households by 2030	226	Solar photovoltaic panels - 10% of households by 2030	226
	Air conditioner - 20% improvement on BAU efficiency	212	Air conditioner - 20% improvement on BAU efficiency	212
Transport	Converting existing bus fleet to biodiesel	7,468	EU carbon emission vehicle standards	4,140
	EU carbon emission vehicle standards	4,140	Converting existing bus fleet to hybrids by 2030	3,007
Waste	Centralised composting	7,878	Landfill gas utilisation	4,334
	Landfill gas utilisation	4,334	Energy from waste (combined heat and power)	3,661

* Based on a central scenario with discount rates of 5% per annnum, annual energy price increases of 2% per annum and no price on carbon.

4. Discussion

4.1 The significance of incentives for low-carbon investment at the local level

This case study of Recife demonstrates that there are many low-carbon measures that are currently available and that generate a significant economic return for investors, even in the absence of enabling pricing policies. Prospective investors in the city of Recife (households, businesses, local authorities or national government) could collectively reduce emissions by 15%, relative to business as usual trends, just by exploiting those measures that generate a real return of 7.5% per annum. If energy prices were to rise and investors to adopt a discount rate as low as 1.4% per annum, city-scale emissions could be reduced by 25% by exploiting the low-carbon options that become economically attractive under these conditions. Particularly in light of Brazil's current economic slowdown, urban mitigation should be a compelling investment opportunity.

Our findings are consistent with those in other cities, including Johor Bahru in Malaysia, Kolkata in India, Bristol in the UK and Palembang in Indonesia (Colenbrander et al., 2015a, 2015b, 2016; Millward-Hopkins et al., 2017). These studies all presume a discount rate of 5% and an annual energy price increase of 2-3%, and identified mitigation potential of up to 25% of business-as-usual emissions. By testing the economic case for low-carbon investment under a range of energy prices and discount rates, this study demonstrates the robustness of the local economic case for large-scale, low-carbon investment. Investors' choice of discount rate and expectations about energy prices do affect the economic feasibility of mitigation measures, but many options prove attractive even under even the least favourable financial parameters. Yet, despite the potential financial returns, the majority of the economically attractive measures identified in these studies have seen limited uptake.

These results imply that investors are either seeking higher returns on their investment than observed market rates suggest, or that other barriers are constraining investment and behavioural change. This is illustrated by the economics of high efficiency air conditioners in Recife. With a low discount rate and rising energy prices, the NPV of investments in high efficiency air conditioners could represent a US$1.7 billion opportunity for Recife over the next fifteen years. Even with high discount rates and constant energy prices, the NPV of this investment would be US$30 million. But investors are commonly choosing not to make the incremental upfront investment necessary to unlock this stream of benefits, suggesting that investors implicitly apply real discount rates exceeding 9% (or nominal discount rates approaching 20%).

The typical economic prescription in response to this market failure would be a carbon price to increase returns from low-carbon investment or various technology policies to improve the technical and economic feasibility of low-carbon measures. These policy levers can be difficult to pull, especially at the city scale. More importantly, the returns from many options already seem to be competitive and the risks low: LED light bulbs, rooftop solar panels, more efficient appliances, CNG buses, European carbon emission standards for private vehicles, recycling and waste-to-energy infrastructure are all proven options, even if their full scope for deployment has not been realised in cities like Recife. Even many of the more complex measures, such as green building standards and BRT systems, have now been adopted in many low- and middle-income cities. We therefore conclude that decision-makers should focus less on incentivising climate action, and more on dismantling the other barriers to change that are stopping investors from exploiting economically attractive low-carbon options.

4.2 The significance of barriers to low-carbon investment at the local level

The barriers to low-carbon investment and behavioural change can come in many different forms beyond incentive structures. These include imperfect information, split incentives, transaction costs, inadequate access to finance, capacity deficits and industry fragmentation (IEA, 2013; IPCC, 2014). Political economy barriers may be even more significant, such as opposition from local industry or a culture of consumerism (Cragg *et al.*, 2012; Dauvergne, 2010; Jenkins, 2014).

Although such barriers may manifest in inflated implicit discount rates (Ürge-Vorsatz et al., 2016), they cannot necessarily be overcome through pricing mechanisms. With significant barriers to technological change, or with deeply embedded behaviours, the levels of carbon pricing needed to incentivise change become politically and economically non-viable. Accordingly, there is a need to design policy instruments that specifically tackle these obstacles to low-carbon investment. Such policies will need to be tailored to the local institutional, legal, economic and cultural context, and to target a range of prospective investors including households, small and medium enterprises, commercial banks and local authorities. In this section, we illustrate how improved access to information, capacity building and enabling financing mechanisms could help to mobilise low-carbon investment in a city like Recife.

Information provision has a critical role to play in raising awareness and enabling action. Better knowledge of environmental impacts or economic savings can stimulate local demand for low-carbon options and contribute to addressing principal-agent problems, such as when a builder or landlord chooses levels of investment in energy efficiency, but purchasers or tenants pay the energy bills. Many local authorities have conducted effective awareness campaigns at the city scale, including Vienna's Städtisches Energieeffizienz Programm and Cape Town's Electricity Saving Campaign. Such campaigns may include workshops, advertisements across a range of media, school programmes and outreach through community-based and non-government organisations. The purpose of these programmes is to promote more sustainable behaviors, either by highlighting financial incentives (such as lower energy bills) or by cultivating norms of environmental citizenship. The former can play an important role in engaging a wider range of stakeholders, but there is also evidence that commodifying sustainability can erode a sense of moral obligation to act on climate change (Sandel, 2012; Millward-Hopkins, 2016). By comparison, appealing to people's environmental concerns can increase compliance and even generate positive spillovers into other forms of environmental behavior (Bolderdijk *et al.*, 2013; Evans *et al.*, 2013). This does not mean that the economic feasibility of different mitigation options is not important, but only that strategic framing of the message is essential to foster a strong environmental identity (Heiskanen *et al.*, 2010).

Better provision of information can provide enough motivation for local actors to develop the knowledge and skills necessary to exploit the most attractive opportunities. However, capacity building initiatives will often be necessary to develop individuals and organisations to match the needs of a low-carbon transition (Simalenga, 2011). At the most basic level, creating a pool of people trained in the design, installation, operation and maintenance of low-carbon measures can spur local uptake (Meah *et al.*, 2008; Mondal *et al.*, 2010). Transnational networks can be a particularly useful platform for sharing knowledge and skills at the city level: ICLEI-Local Governments for Sustainability (of which Recife is a member) and C40 Cities, for instance, have facilitated urban climate action by providing both assistance and visibility to municipal governments (Acuto, 2013; Lee and Koski, 2014; Fünfgeld, 2015).

Even where there is local interest and capacity, prospective investors may be deterred from low-carbon options by large capital and transaction costs. Many mitigation measures have higher upfront costs than conventional alternatives, even if they are more economic in the medium to long term (Jacobs, 2012; Schmidt, 2014). Enabling financing mechanisms can overcome this barrier. Some options include energy performance contracting, dedicated credit lines, revolving funds, insurance and guarantees (Sarkar and Singh, 2010; Schmidt, 2014; Gouldson *et al.*, 2015a; Junghans and Dorsch, 2016). In rarer cases, policymakers can seek to target the product rather than the financial intermediary, for example through bulk purchases, utility financing and negotiated bulk discounts (Sarkar and Singh, 2010). Interventions of this nature depend heavily on horizontal governance arrangements for the requisite knowledge and capacities, specifically partnerships between governments and private actors such as commercial banks, electricity utilities or insurance companies. Such financing mechanisms are also more common at the national than local scale (consider Thailand's Energy Efficiency Revolving Fund or the United Kingdom's Green Deal), demanding cooperation across vertical levels of governance.

City and national governments can adopt and experiment with other policy instruments to overcome barriers to low-carbon investment. However, no single policy can overcome the diverse barriers associated with the full range of mitigation measures available. There is therefore a need for a mix of policy interventions to overcome most if not all barriers at the same time and in a coordinated way. Improving the economic case for action – for example, by introducing a carbon price – might create incentives so strong that system-wide capacities for change develop autonomously. But in most instances, this process of change is unlikely to take place without targeted support to dismantle other barriers to action, at least in the short time frames needed to avoid dangerous levels of climate change. Given the need for urgent action and the waning interest of many national governments, there is a clear basis for municipal governments to adopt a wider range of policy instruments in order to overcome these obstacles. This will enable a wide range of private actors within a given city to take advantage of the economic case for action on climate change.

5. Conclusions

Focusing on Recife in Brazil, we demonstrate that there is a compelling economic case for low-carbon investment at the local level. Prospective investors in this particular city could reduce city-scale emissions by 15%, relative to business as usual by exploiting those opportunities that generate a real return of 7.5% or more. The mitigation potential increases to 25% of city-scale emissions if investors are satisfied with a return of 1.4%.

Yet many of the opportunities identified in this paper are not being exploited despite the scope for significant financial savings. Since The Stern Review was published in 2006, the standard prescription in the face of this problem has been to introduce carbon pricing or adopt technology policies to improve risk-adjusted returns. However, an economic appraisal of individual mitigation measures in Recife suggests that incentive structures are no longer the main determinant of levels of low-carbon investment: returns exceeding 7.5% per annum should be exceedingly attractive in Brazil's current economic climate. Pricing mechanisms may therefore not be enough to drive systems change. Rather, governments need to utilise a range of policy instruments to dismantle the barriers to change, particularly the lack of information, capacities and resources at the local level. Where national governments have deprioritised climate action, the burden of responsibility falls to city governments to create an enabling environment for large-scale, low-carbon investment.

This paper has focused narrowly on the economic case for urban mitigation. While financial feasibility is an important consideration, the attractiveness of low-carbon measures need to be considered in concert with other policy goals: poverty reduction, equity and inclusion, ecological integrity, energy security, mobility and so on. There is a growing body of literature that speaks to the possible co-benefits of well-designed, well-managed climate interventions, particularly with respect to improving air quality (Markandya et al., 2009; Fuzzi et al., 2015), reducing fuel poverty (Ürge-Vorsatz and Herrero, 2012) and enhancing road safety (Litman, 2014). Wherever possible, cities should prioritise mitigation options that will deliver against these wider development objectives. This can stimulate public enthusiasm for low-carbon development, strengthening municipal governments' willingness to explore more ambitious mitigation strategies (Gouldson et al., 2015b).

And greater ambition will be necessary. The widespread adoption of the economically attractive measures identified in Recife and other cities will not achieve the deep emission reductions required to avoid a global temperature increase of 2°C (let alone the 1.5°C commitment of the Paris Agreement), but their cumulative mitigation potential is not insignificant. With an appropriate raft of enabling policies, pursuing these opportunities could enable cities such as Recife to build the commitment and capacities necessary for deeper decarbonisation over the decades to come.

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