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THE ECONOMIC CASE FOR LOW CARBON CITIES

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CONTENTS

EXECUTIVE SUMMARY

In this paper, we conduct a comparative analysis of the results of five recently completed studies that examined the economic case for investment in low-carbon development in five cities: Leeds in the UK, Kolkata in India, Lima in Peru, Johor Bahru in Malaysia and Palembang in Indonesia. The results demonstrate that there is a compelling economic case for cities in both developed and developing country contexts to invest, at scale, in cost-effective forms of low-carbon development. The studies show that these cost-effective investments, for example in building energy efficiency, small-scale renewables and more efficient vehicles and transport systems, could lead to significant reductions (in the range of 14-24%[1] relative to business-as-usual trends) in urban energy use and carbon emissions over the next 10 years. The financial savings generated by these investments would be equivalent to between 1.7% and 9.5% of annual city-scale GDP. Securing these savings would require an average investment of $3.2 billion per city, but with an average payback period of approximately two years at commercial interest rates. The results therefore show that large-scale low-carbon investments can appeal to local decision-makers and investors on direct, short-term economic grounds. They also indicate that climate mitigation ought to feature prominently in economic development strategies as well as in the environment and sustainability strategies that are often more peripheral to, and less influential in, city-scale decision-making.

If these findings were replicated and similar investments were made in cities globally, then we estimate that they could generate reductions equivalent to 10-18% of global energy-related greenhouse gas emissions in 2025. While the studies therefore offer some grounds for optimism, they also highlight the institutional capacities that need to be built and the policy interventions and financing mechanisms that need to be adopted before these opportunities can be exploited. If these were all in place, initiatives to exploit the cost-effective opportunities for low-carbon development in cities could build momentum for change in cities that for a time could be globally significant. However, the studies also demonstrate that, in rapidly growing cities, the carbon savings from cost-effective investments could be quickly overwhelmed – in as little as seven years – by the impacts of sustained population and economic growth. They therefore highlight the pressing need for wider decarbonization (particularly of electricity supply) and deeper decarbonization (through more structural changes in urban form and function) if truly low-carbon cities are to emerge.

1 These figures have been revised and updated, and are thus slightly different from those set out in an earlier version of this paper.

1. INTRODUCTION

Of the 7.1 billion people alive today, more than 3.6 billion live in cities. By 2050 the urban population is predicted to pass 6.7 billion (UN DESA 2014). Forecasts suggest that the vast majority of this urban population – some 5.2 billion people – will live in low- and middle-income countries, where the number of city-dwellers is rising by 1.2 million people per week (WHO 2014). Although the urban population in high-income countries is growing much more slowly, it is still forecast that around 1.2 billion people will be living in cities in high-income countries by 2050 (WHO 2014).

The rapidly growing significance of cities in the developing world, and their sustained importance in the developed world, has great relevance for the mitigation of climate change. Cities are currently responsible for 67–76% of energy use and 71–76% of energy-related greenhouse gas (GHG) emissions (Edenhofer et al. 2014). Given the need for urgent climate action (IEA 2013), urban development decisions taken in the next few years will be crucial in determining the success of global climate mitigation efforts.

Many established cities are now struggling to break away from energy- and carbon-intensive development paths that have resulted in higher energy costs and carbon emissions, as well as traffic congestion, air pollution, poor public health and a range of other negative impacts. Under the right conditions, rapidly growing cities could take early steps to avoid locking themselves into such pathways. However, many cities, and particularly those in the developing world, lack the political will, the financial resources and the institutional capacities needed to do so (Edenhofer et al. 2014). As a result, as the IPCC notes, the adoption of carbon reduction initiatives in cities often depends on city leaders' ability to relate climate change mitigation efforts to local co-benefits (ibid.). A key co-benefit for resource-constrained decision-makers is the ability of investments in energy efficiency and other low-carbon development measures to generate economic benefits for the city.

In this paper, we explore the economic case for large-scale investments in climate mitigation at the city scale – an issue that should be of interest to policy makers, investors and stakeholders at all levels with interests in cities. We do this by conducting a comparative analysis of the results of five recently completed studies that assessed the potential for cost-effective investments in low-carbon measures across different sectors in five cities: Leeds City Region in the United Kingdom, Johor Bahru (including Pasir Gudang) in Malaysia, Lima-Callao in Peru, Palembang in Indonesia and Kolkata in India (see Gouldson, Kerr, Topi et al. 2012; Gouldson, Colenbrander, Papargyropoulou, et al. 2014; Gouldson, McAnulla, Sakai, et al. 2014; Gouldson, Kerr, McAnulla, et al. 2014; Gouldson, Kerr, McAnulla, et al. 2014). These bottom-up studies evaluated the cost and carbon effectiveness of deploying, at scale, a wide array of measures in different sectors. The potential energy, economic and carbon[2] savings were compared to the likely impacts of "business-as-usual" (BAU) modes of development on energy use, energy bills and carbon emissions.

This paper compares the total investment needs, payback periods and potential emission reductions available in the five cities from 2014 to 2025. The analysis highlights some significant differences in the level and composition of energy consumption and GHG emissions in the five cities, but in each case it reveals the presence of substantial opportunities for economically attractive forms of low-carbon development. While these cities cannot be said to fully represent the variety of urban centres that exist today, they are geographically diverse; are found in high-income (the UK), upper middle-income (Malaysia and Peru) and lower middle-income (India and Indonesia) countries; and are pursuing a range of development modes. The comparative analysis therefore illustrates a range of the different levels and trends in economic growth, energy consumption and carbon emissions found in many cities around the world. Our analysis also puts the findings in the broader context of climate mitigation. In particular, we examine whether, and how, these economically attractive opportunities could lead to the deeper, transformative low-carbon transitions that will be needed in the world's cities if we are to achieve climate mitigation targets in the longer term.

Section 2 outlines the methodologies employed for the city studies and this comparative analysis. Section 3 presents and compares the headline findings from the five city studies, including total investments needs,

2 We consider the carbon emissions from different forms of energy consumption and some non-carbon GHG emissions from the industrial and waste sectors. We consider measures that reduce any of these emissions to be "low carbon measures".

economic returns, payback periods and carbon savings relative to BAU trends. It also seeks to contextualize the impact of economically attractive forms of low-carbon development in cities by evaluating the time that it will take carbon emissions to regain the levels they would have achieved under BAU conditions after very substantial investments in low-carbon measures have been made. Section 4 looks in more detail at each of the five cities in turn, discussing specific low-carbon opportunities available in each city and focusing on a sector of particular importance in each one. Section 5 considers the global implications of this research and identifies some of the technical, financial and institutional capacities that would need to be developed if the economically attractive options are to be widely exploited, and in a way that moves the city towards deeper, wider decarbonization. This underpins a discussion of the policy tools and financing mechanisms available to decision-makers. Section 6 considers two different scenarios for large-scale low-carbon investment in cities, and thereby explores the potential contribution that economically attractive measures could play in driving more transformative change.

2. METHODOLOGY

The basic methodology used in the city studies includes three stages:

1. An assessment of recent trends in the city's energy use, costs and GHG emissions and of the implications of these trends continuing for the next decade (the BAU baselines);
2. An evaluation of the costs, benefits and carbon saving potential of a wide range of the low-carbon measures that could be adopted in different sectors in the city in the next decade; and
3. An aggregation of the findings and the presentation of the economic case for investment in these options at scale in different sectors in the city in the next decade.[3]

This comparative analysis additionally includes a new calculation, the Time to Reach BAU Levels of Emissions (TREBLE) point, for different levels of low-carbon investment in each city. This is explained in detail below.

2.1 Setting the scope and boundaries of the city studies

Geographically, each study focused on a metropolitan area or city region determined in conjunction with local government partners. This allowed us to consider energy use within the broader travel to work area that was under the influence of the metropolitan government.

Temporally, the studies focused on the medium term, basing BAU calculations on the last 10-15 years and assessing the impacts of adopting low-carbon options in the next 10-15 years.[4] This helped to ensure that the findings are relevant to current decision-makers without making the study so long-term in its orientation that it loses practical relevance to current political leaders and policy-makers.

Economically, each study focused on the direct, private financial costs and benefits of the different low-carbon measures that could be adopted in each city. Many such measures have potentially significant social co-costs and co-benefits, for example in the form of distributional consequences, environmental impacts and wider economic multiplier effects. These are not formally considered in the quantitative analysis presented here. This is not meant to downplay their significance: the presence of co-benefits such as improved public health or employment creation would strengthen the case and the presence of co-costs such as deteriorated public health or induced skills shortages could weaken the case for investment in particular measures. Careful design and delivery will be needed to maximize co-benefits and minimize co-costs. However, the narrower analysis presented in the studies reflects the reality that often the direct private economic case has to be demonstrated before policy-makers can start to consider potential investments and their wider impacts.

Technically, in terms of carbon accounting, each of the studies considered GHG emissions from the metropolitan area, including those from direct consumption of fuels and waste management facilities within local authorities' reach (so-called Scope 1 emissions) and those produced by generating the electricity consumed within the city (Scope 2 emissions). The studies therefore took into account the energy mix, carbon intensity and the production and transmission efficiencies of electricity supply to the transmission grid or network serving the city. None of the studies considered embedded energy or carbon in the goods or services produced or consumed within the city (Scope 3 emissions). The studies thus focused on territorial emissions within each city, with consumption-based emissions being considered for electricity use only.

2.2 Calculating business-as-usual trends

The studies first sought to map the levels and composition of energy supply and demand in each city. The BAU baselines used in this comparative analysis are based on an extrapolation of trends between 2000 and 2014 through to 2025 in each city. Data were collected from academic literature, government agencies and

3 The basic methodology was developed as part of a study commissioned for the Leeds City Region in 2010. See Gouldson, Kerr, Topi et al. 2012.

4 To enable comparisons between the results of the 5 studies, the temporal boundaries of some of the studies have been altered so that they all consistently consider the period from 2000 to 2025.

industry reports to develop these baselines, which were then reviewed by project steering committees and stakeholder panels to ensure their accuracy and relevance. Data sources are fully detailed in the reports for each city study (Gouldson, Kerr, Topi et al. 2012; Gouldson, Colenbrander, Papargyropoulou, et al. 2014; Gouldson, McAnulla, Sakai, et al. 2014; Gouldson, Colenbrander, Sudmant, et al. 2014; Gouldson, Kerr, McAnulla, et al. 2014). Factors such as economic growth, population growth, changing consumer behavior and changing levels of energy efficiency were taken into account.

2.3 Identifying and evaluating low-carbon options

Longlists of the low-carbon measures that could be adopted in the residential, commercial, industrial, transport and waste sectors of each city were developed for each city.[5] These lists were derived from extensive literature searches and input from in-country partners. In consultation with the project steering groups and stakeholder panels, the longlists were cut down to shortlists of those measures that were considered appropriate for local climates, cultures or socio-economic structures. The performance of shortlisted measures was then assessed based on their capital, running and maintenance costs, focusing on the marginal costs of adopting a lower-carbon alternative and the reductions in energy use, energy bills and carbon emissions that could be achieved were they to be deployed at city scale.

For the Leeds City Region, data on the performance of different low-carbon options and the scope for their deployment were drawn from models that had already been developed for the UK Department of Energy and Climate Change and the UK Committee on Climate Change. The data were subjected to review by a project steering committee and other stakeholders at the local level, and adjustments were made where necessary to update figures and ensure local relevance. Such models did not exist for the other cities, so data were instead generated through extensive literature reviews. In each case, these data were reviewed, updated and adjusted for local relevance by the project steering committee and other stakeholders, including representatives of national governments, city authorities, development agencies, industry groups, civil society organizations and local universities. Data sources and full lists of participants on steering groups and stakeholder panels are fully detailed in the reports for each city study.

As each measure could be in place for many years, changing real energy prices and carbon intensities of electricity were considered. A standard real (i.e. after inflation) private interest rate of 5% was used to evaluate the economic case for investment.

The estimates developed during these processes were then used to develop an assessment of the likely lifetime economic and carbon savings from each option when deployed at scale. Based on this, measures were put into "league tables" ranking them in order of i) the carbon savings that they generate over their lifetime (total emissions reduction) and ii) the cost-effectiveness of these lifetime carbon savings (the value of economic savings per unit of emissions reduction). These league tables provided an indication of the potential impacts of deploying any individual measure independently, i.e. without relying on the adoption of any other measure. Short versions of the league tables for the five cities are included in Annex 1.

2.4 Calculating potential savings at the city scale

The league tables reflect the cost-effectiveness of the carbon savings from a particular measure, but to generate these we also assess the cost-effectiveness of the measures themselves in purely economic terms. We define a cost-effective measure as one that generates financial returns over its lifetime greater than its lifetime costs, with costs and benefits assessed using a private real interest rate of 5%. The cost-effective scenarios used in this comparative analysis were developed by aggregating the investment needs, energy bill savings and emissions reductions from deploying the cost-effective measures available to a city.

When determining the aggregated potential savings across a sector or across the city economy, we factored in the effect of each measure on the potential energy savings of other measures to develop realistic assessment of their combined impact. For example, when calculating the carbon savings from adopting mandatory energy performance standards for air conditioners, the reduced cooling load from

5 Low-carbon measures in the electricity sector were also considered in the 4 developing country cities, but as generation is generally beyond the control of city authorities, they are not considered in this analysis. Low-carbon measures for the waste sector were not considered in the Leeds City Region study.

the introduction of green building standards was taken into account. Similarly, some cost-effective measures were not included in the cost-effective scenario because they were mutually exclusive with more economically attractive low-carbon options.

A second scenario was developed to determine the potential economic and carbon savings that could be realized in each city if the returns from the cost-effective scenario were reinvested in additional measures. This produced a "cost-neutral" bundle of measures, which we define as a bundle of measures that could be adopted at no net cost on commercial terms over all of the measures' lifetimes, with the returns from the cost-effective investments being used to pay for some non-cost-effective investments. These bundles were compiled by working down through the league tables of the cost-effectiveness of carbon savings, that included assessments of the cost-effectiveness of the measures themselves, with us adding measures to the bundle until all the savings from the cost-effective options had been re-invested.

While this analysis considers costs and benefits across the city as a whole, with the city itself being seen as the functioning economic unit, it should be noted that cost-recovery mechanisms would need to be in place for financial savings from cost-effective low-carbon measures to be captured and reinvested or fed back to the investors.

2.5 The TREBLE point

It is important to stress that while low-carbon investments could reduce energy use and carbon emissions in the short to medium term, in the longer-term the contribution of such investments may be outweighed by the impacts of on-going population and economic growth. This could be the case even if ongoing growth after low-carbon investment is more energy-efficient and less carbon-intensive than it would have been without such investment. To consider the impacts of low-carbon investments in the context of ongoing growth, we develop the concept of the TREBLE point. This compares the time taken for emissions with investment in low carbon measures to reach the level that would have been realized without such investment under the BAU scenario in a reference year, in this case 2025. A positive number suggests that with investment the BAU level of emissions forecast for 2025 would still be realized but a number of years later; a negative number suggests that with investment the BAU level of emissions forecast for 2025 would be realized a number of years earlier. A positive value indicates that emissions with and without low carbon investments are increasing over time, a negative value that they are decreasing over time. If emissions after investments are unlikely to reach the BAU reference point in the foreseeable future, there is no TREBLE point.

In calculating TREBLE points for the cost-effective and cost-neutral scenarios for each city, we have assumed that the cities maintain the lower-carbon intensity of growth that comes with investment in low-carbon measures. This is plausible given the long lifespan of many options, such as green building standards, mandatory energy performance standards and public transport infrastructure.

Given the rapid accumulation and long life of carbon in the earth's atmosphere, the immediate carbon savings from these investments are important in themselves. The analytical value of the TREBLE point lies in revealing the amount of time that a particular low-carbon investment can gain for a city seeking overall and permanent emission reductions in the context of ongoing growth. Economically attractive low-carbon measures would buy such a city time, but to sustain cuts in its total emissions in the longer term in a context of ongoing growth, it would have to invest in further measures with greater transformative potential within the period described by the TREBLE point.

2.6 Assumptions and limitations

The results of each study, and therefore also of the comparative analysis presented here, depend to some extent on the quality of the data available and the assumptions made. The studies assume, for example, that growth in the different cities can continue in the near future as it has in the recent past; in practice, many cities might encounter structural limits to growth such as gridlock in the transport system. Similarly, the studies assume that the impacts of economic growth and human development on energy use will continue to 2025 as they have in the recent past so that, for example, we project a consistent relationship between growth in income per capita and rising levels of appliance ownership and use. The calculations also assume that real prices (including energy) will rise at constant rates based on local inflation rates and historical trends, and that there will be no significant expansions in or improvements to the array of low-carbon measures available.

These significant assumptions may or may not prove to be true, but were necessary to make the analysis feasible. They are, however, conservative with respect to the returns of low-carbon investment; for example, increasing gridlock will enhance the social co-benefits of large transport infrastructure investments, and technical improvements to renewable energy technologies are likely to increase their economic attractiveness and carbon savings. The assumptions are fully detailed in the appendices for each city study (Gouldson, Kerr, Topi et al. 2012; Gouldson, Colenbrander, Sudmant, et al. 2014; Gouldson, Colenbrander, Papargyropoulou, et al. 2014; Gouldson, McAnulla, Sakai, et al. 2014; Gouldson, Kerr, McAnulla, et al. 2014).

Our results are intended to offer useful insights into broad trends and the scale of the opportunity for climate action at the city scale, and they can be used as a broad-brush guide for decision-making in each of the cities studied. However, we do not claim that the data presented are complete, robust or detailed enough to underpin, for example, specific investment decisions.

3. RESULTS

3.1 Business-as-usual trends

BAU baselines for economic development, energy consumption, emissions intensity of economic activity and total carbon emissions for each of the five cities are presented in Figure 1. The averages for member countries of the Organization for Economic Co-operation and Development (OECD) are also shown for reference. According to our BAU projections, in the period from 2014 to 2025:

- Average GDP per capita will increase in all five cities.
- Average per capita energy consumption will rise significantly in Johor Bahru and Palembang, driven by industrial expansion, and rise slightly in Kolkata, Lima and Leeds. All cities will remain significantly below OECD averages.
- Average per capita emissions will continue to rise in all cities except Leeds, where it will fall markedly in line with OECD trends. Emissions per capita in Johor Bahru will exceed the average in OECD countries.
- The emissions intensity of economic activity will fall in all cities except Palembang, where fuel switching to more carbon-intensive energy sources is anticipated.

Putting these baselines together reveals the trajectories for absolute emissions levels in each city between 2014 and 2025 under BAU conditions. Absolute carbon emissions will increase in the four developing world cities: by 54% in Kolkata, 52% in Lima, 84% in Johor Bahru and 165% in Palembang. In Leeds, however, they will fall by 13%.

More detail about relevant developments in each city is given in the case studies in Section 4.

3.2 Comparing the economic cases for low-carbon investment in the five cities

In contrast to the BAU scenarios, the economic cases for low-carbon investment in the five cities show some striking similarities. The summary results of the economic analysis for investments in cost-effective and cost-neutral bundles of measures are presented in Table 1.

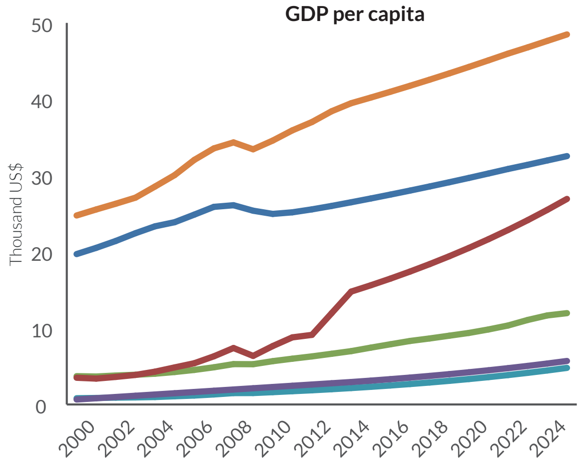
These results suggest that there are very significant opportunities for cities to attract investment through economically attractive initiatives that would cut their carbon emissions. The package of cost-effective investments would pay for themselves through the energy that they save quickly, in one case in a matter of a few months, and they would generate carbon savings of 14%-24% (relative to BAU trends). As most of the low-carbon measures considered have lifespans beyond their payback periods, the investments made would carry on generating both financial and carbon savings over a much longer period.

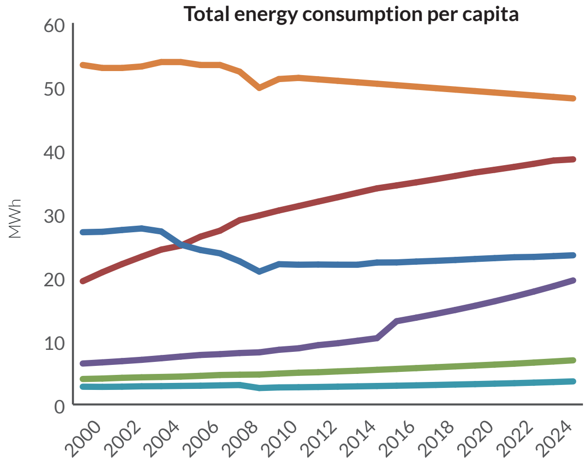
If the savings from these cost-effective investments were captured and reinvested in further low-carbon measures up to the point where all investments would be cost-neutral then levels of investment would at least double in most of the cities. While the payback periods of these cost-neutral bundles of investments would be longer – up to eight years – they could reduce emissions by 21-45% relative to BAU trends.

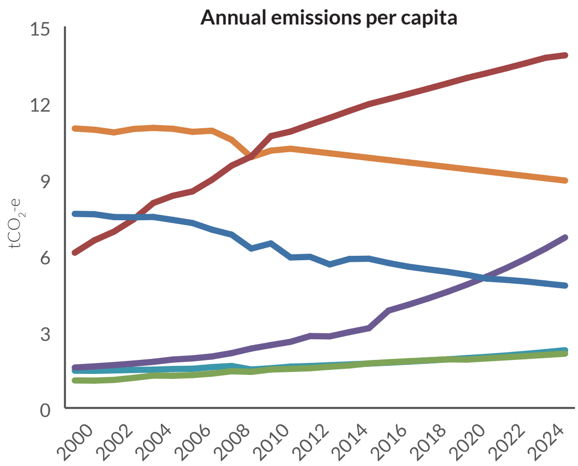
3.3 TREBLE points: The impacts in a longer-term perspective

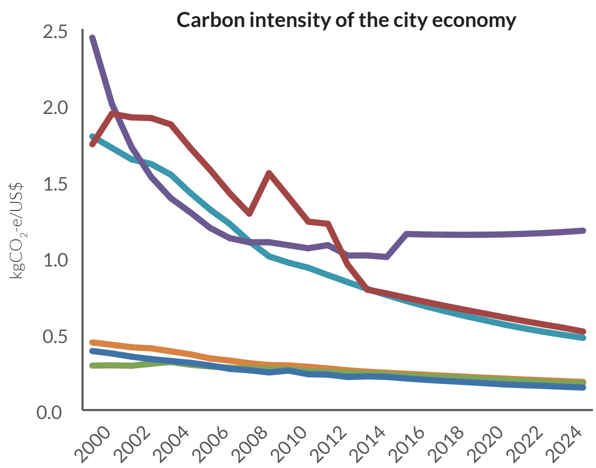
Analysis of the TREBLE points reveals that with cost-effective investments, the four developing world cities could keep emissions below the BAU levels projected for 2025 for a further 7 to 15 years (see Figure 2 and Table 1). However, the analysis also shows that the impacts of sustained population and economic growth would then offset the improvements in energy efficiency and carbon intensity generated by the cost-effective investments. For the Leeds City Region, where BAU levels of emissions are falling, investing in the cost-effective options could bring the reduced BAU level of emissions projected for 2025 forward by as much as six years.

The prospects for cost-neutral levels of investment to reduce overall emissions in the longer term are even more compelling. In the cost-neutral scenarios, Palembang has a TREBLE point of 10 years and Lima of 15









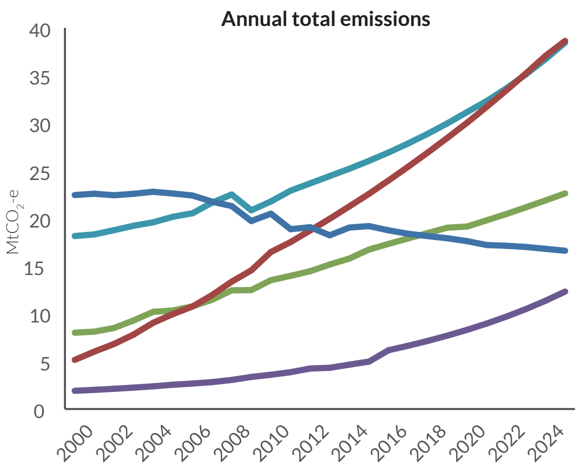


Figure 1: Historic and projected business-as-usual trends in GDP, emissions and energy consumption for five cities, 2000–2025

Table 1: Summary of the estimated costs and benefits of two levels of low-carbon investment in the five cities

	Leeds	Johor Bahru	Lima	Palembang	Kolkata
Cost-effective scenario					
Investment needs (US$ billion)	7.7	1.0	5.0	0.4	2.0
Investment needs (% of city GDP)	8.9	3.7	7.5	8.8	6.3
Annual savings (US$ billion)	1.9	0.8	2.1	0.4	0.5
Annual savings (% of city GDP)	2.2	2.9	3.2	9.5	1.7
Payback period (years)	4.1	1.3	2.4	<1	3.9
Carbon savings in 2025 ($MtCO_2$-e)	2.6	9.4	3.5	3.2	7.8
Carbon savings in 2025 (% of BAU)	15.6	24.2	14.7	24.1	20.7
TREBLE point (years)*	-6	11	7	8	15
Cost-neutral scenario					
Investment needs (US$ billion)	18.1	5.6	10.8	1.5	3.6
Investment needs (% of city GDP)	21	20.8	16.3	33.6	11.4
Annual savings (US$ billion)	2.5	0.8	2.4	0.5	0.6
Annual savings (% of city GDP)	2.9	3.1	3.6	10.2	1.8
Payback period (years)	7.3	6.8	4.5	3.3	6.2
Carbon savings in 2025 ($MtCO_2$-e)	3.6	17.5	5.2	3.7	13.6
Carbon savings in 2025 (% of BAU)	21.8	45.4	22.4	28.3	35.9
TREBLE point (years)*	-7	NA	15	10	NA

* Time to Regain BAU Levels of Emissions: the number of years earlier or later that a city reaches the BAU level of emissions it would have had in 2025, due to the emission reductions from low-carbon investments. A positive value indicates that anticipated emissions growth has been pushed back. A negative value indicates that anticipated emission reductions have been brought forward. NA indicates that emissions levels after low-carbon investment do not regain the levels projected under BAU conditions for the foreseeable future.

years. In Johor Bahru and Kolkata, there is no TREBLE point in the cost-neutral scenario: in other words, if the impact of the cost-neutral bundle of measures is sustained, these cities could effectively shift to low-carbon development trajectories at no net cost. This is an even more substantial contribution, as it suggests that, in some cities at least, economically neutral levels of low-carbon investments could have a durable impact on carbon emissions over the longer term.

It is worth emphasizing that the emission reductions from these low-carbon investments represent a substantial contribution to climate mitigation. With the exploitation of all cost-effective low-carbon measures, the five cities could avoid emissions of between 2.6 and 9.4 $MtCO_2$; with the further deployment of all cost-neutral options, the five cities could avoid emissions of between 3.6 and 17.5 $MtCO_2$-e (see Figure 2 and Table 1). While these are very significant reductions in carbon emissions, the analysis of TREBLE points makes it clear that cities cannot deliver sustained emission reductions by only exploiting economically attractive options. It will be necessary to invest in less economically attractive options, and possibly wider and deeper changes in urban form and function, if growing cities want to achieve deeper cuts in their carbon emissions in the longer-term.

3.4 Global implications

This comparative analysis indicates that there is scope for economically attractive investments to reduce energy use, energy bills and carbon emissions, relative to BAU trends, in diverse cities at different stages of development. If the opportunities available to the five case study cities are broadly representative, and all cities were to identify and exploit similar opportunities, then this would lead to very substantial investments in the low-carbon economy and reductions in carbon emissions that would be significant at the global scale.

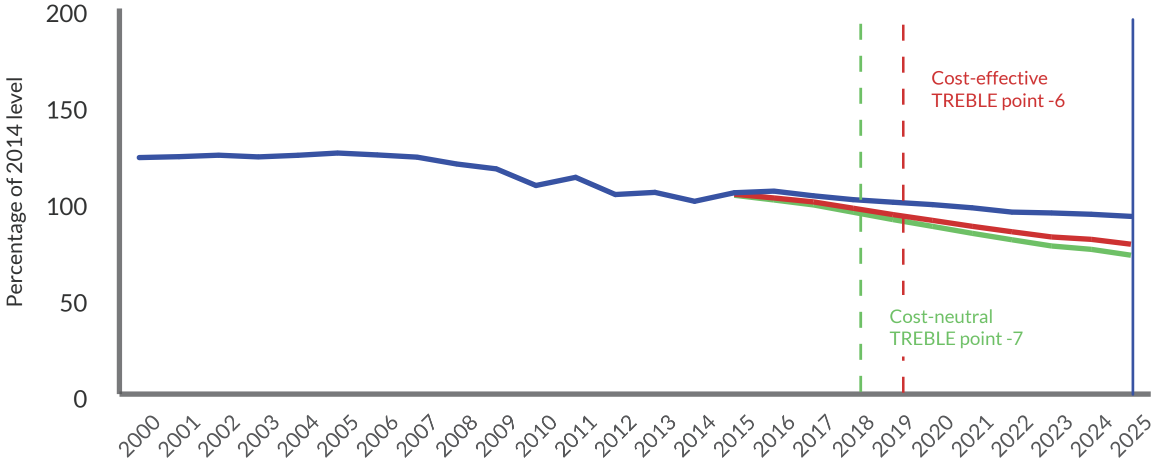
Specifically, if 71–76% of global energy-related GHG emissions come from cities (Edenhofer et al. 2014), and cities could be reduce their GHG emissions by 14-24% through cost-effective investments (as in our small sample), then very cautiously we could estimate that cities could achieve reductions equivalent to 10-18% of global energy-related emissions in 2025. Further, if GHG reductions of 22–45% are available through cost-neutral levels of investment in all cities, then – equally cautiously – we could estimate that cities could deliver carbon savings equivalent to 15–34% of global energy-related emissions at no net cost.

Studies such as the Stern Review (Stern 2007) have illuminated the broader longer-term economic logic for addressing climate change at the global scale. While this has been widely discussed, it is not always clear that the logic holds for specific investment decisions at the local level. The findings of the comparative analysis presented here, and those of the individual city studies, therefore provide an important complement to such analyses by demonstrating the economic case for climate action at the sub-national level. Our findings suggest that investment in the early stages of the low-carbon transition can appeal to local decision-makers and investors on direct, short-term economic grounds. This indicates that climate mitigation ought to feature prominently in economic development strategies as well as in the environment and sustainability strategies that are often more peripheral to, and less influential in, city-scale decision-making.

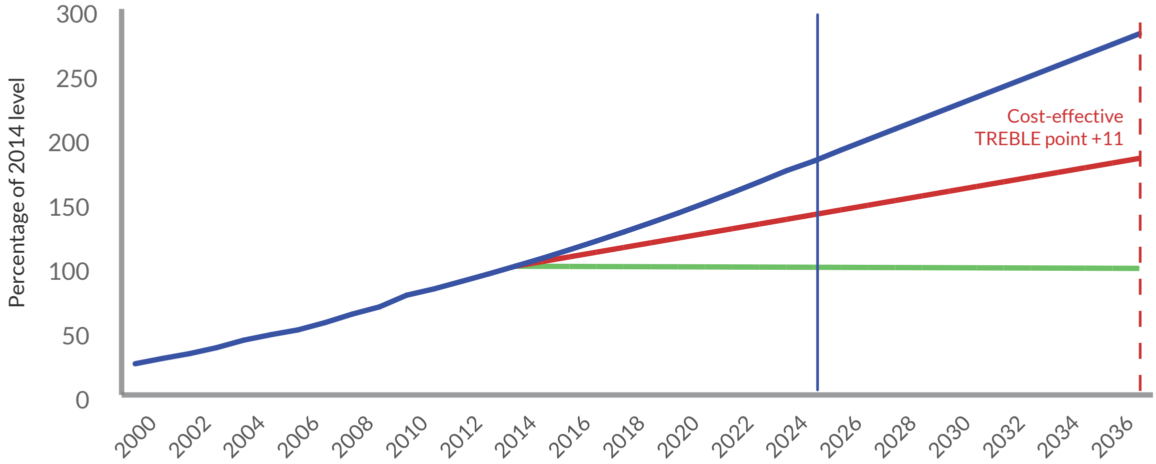
Figure 2: Projected carbon trajectories in five cities under business-as-usual, cost-effective and cost-neutral scenarios, showing TREBLE point (reference year: 2025)

Note: TREBLE = Time to Reach Business-as-Usual Levels of Emissions

Leeds



Johor Bahru



Lima

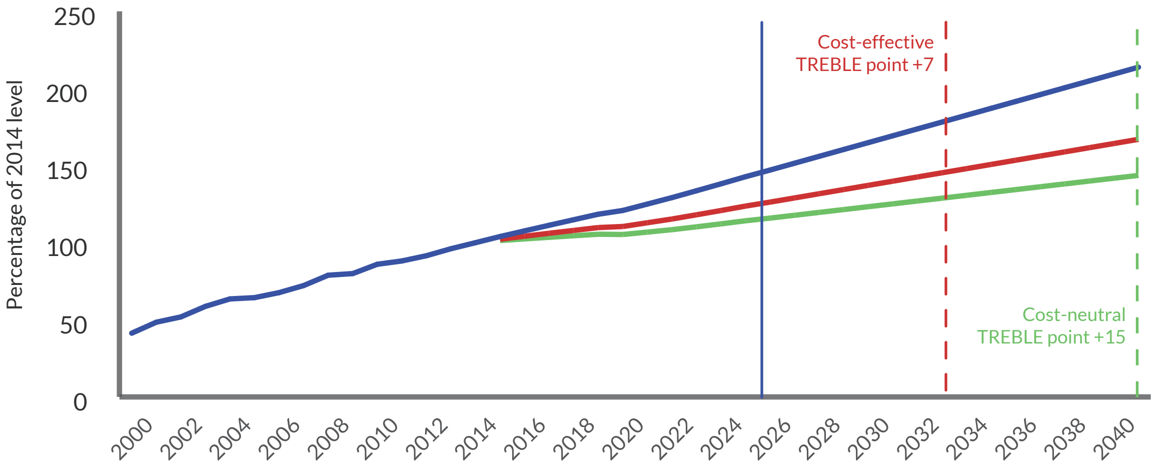
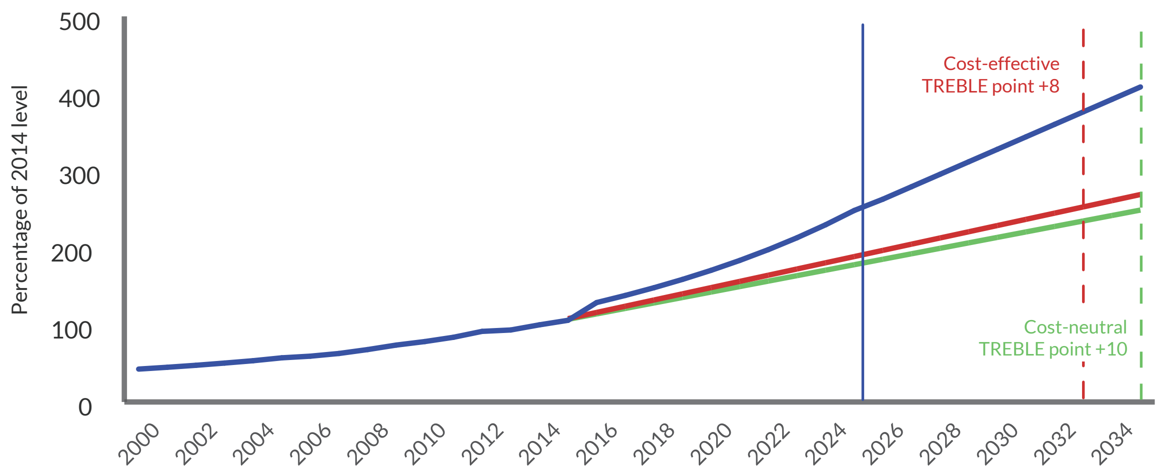
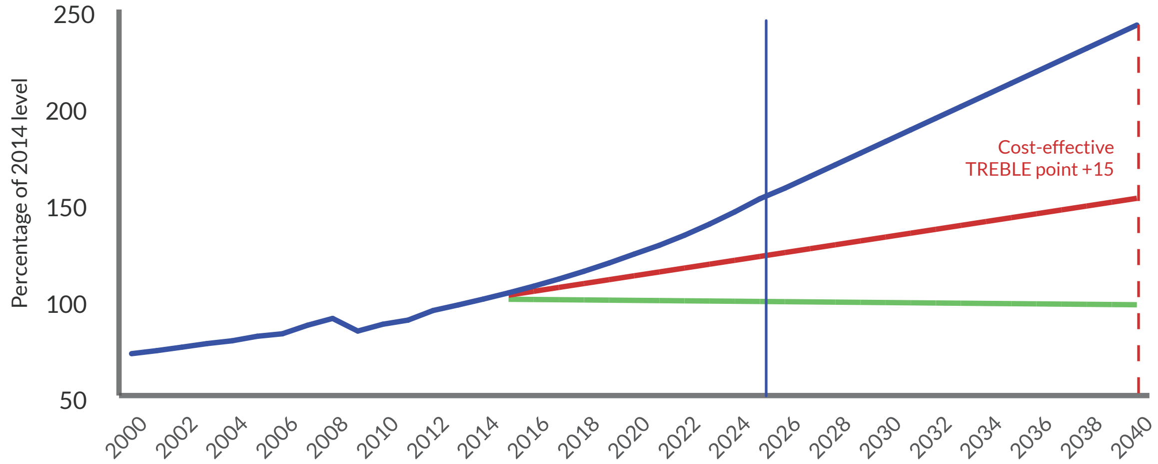


Figure 2, continued

Palembang





baseline and business-as.usual scenario
cost-effective scenario
cost-neutral scenario

4. CITY CASE STUDIES

This section provides more detail about each of the five cities studied. We present the broader context of the city to illustrate its relative carbon intensity and development level, and explore the economic and carbon savings of deploying the cost-effective and cost-neutral bundles of low-carbon measures. Each case study also zeroes in on a particular sector where the most interesting opportunities can be found in that city. Summaries of key data and findings for each city can be found in Annex 1.

The Leeds City Region, UK

The Leeds City Region[6] has a population of over three million and an economy worth over £52 billion (US$86.2 billion)[7], which is approximately 5% of the UK economy. Per capita GDP in the area is approximately £17,000 (US$26,500) and per capita energy consumption is 75% of the OECD average. The carbon intensity of energy in Leeds is 0.27tCO_2-e/MWh but this figure is falling as lower-carbon electricity sources come online. The city region's aggregate energy use is relatively stable, but its annual energy bill of £5.4 billion (US$8.4 billion) – approximately 10% of city GDP – is steadily increasing.

Leeds faces many of the energy and carbon challenges of other established cities in the developed world. It has a largely de-industrialized, service-based economy with relatively high levels of wealth, energy consumption and carbon emissions when compared to world averages. Its infrastructure is extensive but relatively old, and may need to be substantially retrofitted to reduce emissions intensity. For example, much of the housing stock was built before 1920 and is poorly insulated and energy inefficient. Moreover, Leeds is the largest city in western Europe without a mass transit system. Transitioning to a low-carbon city therefore demands substantial investment. However, ongoing decarbonization of electricity supply at the national scale in the UK means that the city's annual emissions are falling in absolute terms.

We find potential for £4.9 billion (US$7.7 billion) of cost-effective investments in different energy efficiency, renewable energy and other low-carbon measures within Leeds. These would generate annual savings of £1.2 billion (US$1.9 billion), meaning that they could pay for themselves in around four years. If these investments were made, we estimate that Leeds could reduce its annual carbon emissions by 2025 by 15.6%, relative to BAU levels. The emission savings would be distributed among the commercial (30.4%), domestic (29.5%), industrial (33.2%) and transport (6.9%) sectors. A cost-neutral package of measures would mobilize £11.6 billion (US$18.1 billion) of low-carbon investments and would deliver annual emission reductions of 21.8% in 2025 relative to BAU levels at no net cost to the city.

More detail on the Leeds City Region study can be found in Gouldson, Kerr, Topi et al. (2012).

6 Leeds City Region is a functional economic area that includes the local authority districts of Barnsley, Bradford, Calderdale, Craven, Harrogate, Kirklees, Leeds, Selby, Wakefield and York.

7 Calculations at an assumed exchange rate of £1 = US$1.56.

Sector focus: Residential buildings in Leeds

Numerous opportunities exist to reduce households' energy use and carbon footprints within the Leeds City Region. These include investments in the fabric of the built environment (i.e. through loft and wall insulation, double glazing), in more energy-efficient appliances and in changing behaviour, such as turning off appliances and turning down thermostats.

The study shows that mini-wind turbines with a feed-in tariff are the most cost-effective measure in the domestic sector, but because the scope for deployment is comparatively small, the aggregated carbon saving potential is low. Biomass boilers with a renewable heat incentive are the next most cost-effective measure for the sector and offer large potential carbon savings. Reducing household heating levels by 1°C would also offer very significant potential for cost-effective carbon savings, as would solid wall insulation, although investment in this measure would need to be cross-subsidized by the cost-effective low carbon measures.

Relative to BAU trends, cost-effective low-carbon investments in the domestic sector could reduce city-scale emissions by 5.7% by 2025. This would require investment of £1.1 billion (US$1.7 billion), generating annual savings of £400 million (US$626 million), paying back the investment in less than three years and generating annual savings for the lifetime of the measures. The domestic sector could reduce emissions by a further 2.2% relative to BAU trends by 2025 through a cost-neutral bundle of investments. This would mobilize low-carbon investment of £3.6 billion (US$5.6 billion) and generate annual savings of £556 million (US$870 million).

Johor Bahru, Malaysia

Johor Bahru[8] is the third largest city in Malaysia, and serves as an important industrial, logistics and commercial centre. The population is currently 1.5 million but this is expected to grow to 2.8 million by 2025. Planned urban expansion is intended to exploit Johor Bahru's strategic location near Singapore, the East China Sea and the Straits of Malacca. Massive additional investment in urban infrastructure is planned over the next decade in order to meet the needs of the growing population and diversifying economy.

The city enjoys high growth rates after becoming the focus of Iskandar Malaysia regional economic corridor. Per capita incomes in the area are 48,880 Malaysian ringgit (MYR; US$14,790)[9] and per capita energy consumption is 70.2% of the OECD average in 2014. Economic and population growth will see substantial increases in absolute levels of emissions (83.8%), energy use (79.4%) and energy bills (139.9%) in Johor Bahru over the period 2014 to 2025.

We estimate that Johor Bahru could reduce its carbon emissions by 24.2% in 2025, relative to BAU trends, through cost-effective investments worth MYR3.3 billion (US$1.0 billion). These would generate annual savings of MYR2.6 billion (US$0.77 billion), with the emission reductions distributed among the commercial (1.2%), domestic (19.6%), industrial (18.3%), transport (52.2%) and waste (8.7%) sectors. Reinvesting the returns on these investments in other low-carbon measures could enable investment in a cost-neutral package of measures worth MYR18.5 billion (US$5.6 billion), which would deliver emissions reductions of 45.4% relative to BAU at no net cost to the city.

More detail on the Johor Bahru study can be found in Gouldson, Colenbrander, Papargyropoulou, et al. (2014).

8 For the purposes of this review, Johor Bahru includes the administrative districts of Johor Bahru and Pasir Gudang.

9 Calculations at an assumed exchange rate of MYR1 = US$0.30

Sector focus: Industry in Johor Bahru

Industry is the largest energy user and second largest source of emissions in Johor Bahru. Globally, industry contributes 19% of total GHG emissions (IPCC 2007), but in Johor Bahru, it contributes as much as 45%. This is unsurprising, since energy-intensive processing and manufacturing drive much of the city's growth. However, there are substantial opportunities to improve industrial energy efficiency, which would help Iskandar Malaysia meet its emission reduction targets and support other goals such as economic competitiveness.

We find that the industrial sector in Johor Bahru could reduce emissions by 10.8%, relative to BAU trends through cost-effective investments. This would require investment of MYR1.3 billion (US$377.8 million), generating annual savings of MYR1.3 billion (US$396.3 million), paying back the investment in less than one year and generating annual savings for the lifetime of the measures. The industrial sector could reduce emissions by a further 24.5% through the cost-neutral investment package, at a total investment of MYR6.6 billion (US$2.0 billion). This bundle of measures would generate annual savings of MYR1.5 billion (US$465.3 million).

Realizing some of these savings will require significant investments in new technologies. This is particularly true for the petroleum refinery and petrochemical industry, which would benefit from more efficient pumps, compressors, furnaces, boilers, heat exchangers and utilities. These would all pay for themselves within six years – even at current low energy prices. Other low-carbon measures entail only small additional operational costs in return for large energy and carbon savings. This is particularly apparent in the rubber industry, where leak prevention and lowering functional pressure in boilers could yield large emissions reductions.

Lima-Callao, Peru

With a population of 9.2 million, Lima Metropolitan Area[10] is the fifth largest city in South America and by far the largest metropolitan area in Peru, accounting for 51% of national GDP and 84% of the tax base (INEI n.d.). While Lima's GDP per capita reached approximately 18,590 Peruvian Nuevo Sol (PEN; US$6,990)[11] in 2014, provision of housing, transport and sanitation infrastructure has not kept pace with the increasing population. Absolute poverty in the city fell from 44.8% in 2004 to 15.7% in 2011, but approximately one in ten people continues to lack access to water and electricity (Sedepal 2010). There has also been a substantial expansion of informal settlements on the periphery of the city.

Lima has distinct advantages in the shift towards a low-carbon economy, in the availability of low-cost, low-carbon (0.24tCO_2-e/MWh) electricity, largely generated from hydropower and natural gas, and a climate in which neither heating nor air conditioning are widely needed. Projected BAU trends suggest that, while energy consumption per capita grew 32% between 2000 and 2014, current levels are only 10% of the OECD average. However, economic development and a growing population will see substantial increases in absolute emissions levels (52%), energy use (48%) and energy bills (92%) over the period 2014-2025.

We estimate that, compared to BAU trends, Lima could reduce its carbon emissions by 2025 by 14.7% through cost-effective investments of PEN13.2 billion (US$5.1 billion). These investments would generate savings of PEN5.5 billion (US$2.1 billion), with the emission reductions distributed among the commercial (10.5%), domestic (15.3%), industrial (23.9%), transport (42.5%) and waste (7.9%) sectors. We calculate that reinvesting the returns from these investments in other low-carbon measures would enable an extra PEN 19.72 billion (US$7.1 billion) of investments that would deliver emission reductions of 22.4% relative to BAU levels at no net cost to the city.

More detail on the Lima-Callao study can be found in Gouldson, McAnulla, Sakai et al. (2014).

10 Lima Metropolitan Area includes Lima, the capital city, and Callao, the main seaport of Peru.

11 Calculations at an assumed exchange rate of PEN1 = US$0.36.

Sector Focus: Transport in Lima

Lima has seen tremendous growth in transport demand since 2000. Vehicle numbers have increased on average 4.6% per year while the number of trips completed each day in the city has risen on average 8.0% per year. A continuation of recent trends would mean that Lima faces an increase of 36% in transport emissions, of 76% in fuel expenditure and a 9% reduction in travel speeds by 2025, along with a significant rise in air pollution. Some recent and anticipated investments in Lima's transport system will have a significant impact, including a bus rapid transit (BRT) scheme, the expansion of the Lima metro network, and the implementation of Euro IV emissions standards for heavy-duty vehicles. We find that the transport sector in Lima will reduce emissions by 15%, relative to a BAU scenario, with the implementation of these measures.

Without further investments, however, a growing population and rising vehicle ownership rates risk overwhelming Lima's already congested transport infrastructure. To avoid this outcome, policy-makers in Lima have several economically attractive investment options. Emissions could be reduced by 26% relative to BAU trends through additional, cost-effective investments of PEN2.9 billion (US$1.1 billion). These could generate economic savings of PEN2.3 billion (US$832 million), paying back the initial investment in 2.6 years and generating annual savings for the lifetime of the measures. Emissions could be reduced by a further 5% relative to BAU through exploitation of a cost-neutral investment package.

Improving the energy efficiency of informal public transport networks is one commercially attractive intervention. Combis (large, privately-owned minibuses) accommodated approximately 20% of trips in Lima in 2014. Our analysis suggests that replacing these with modern buses would require an investment of PEN978 million (US$372 million) and yield carbon savings of 357ktCO_2-e in 2025. Congestion tolls in city centres are also attractive to urban planners because they raise funds for public transport investments as well as reducing congestion. Although politically contentious, this policy could reduce emissions by over 400ktCO_2-e in 2025 while raising more than PEN263 million (US$100 million). Meanwhile, additional investments to enhance the safety of cyclists (such as separated cycleways, intersection improvements, and driver education) could dramatically increase the number of cyclists using existing cycleways in Lima and serve as a flagship for climate action, as they have in Bogotá and London.

Palembang, Indonesia

Palembang is the seventh largest city in Indonesia, the capital and major industrial centre of the state of South Sumatra, and an important port for the island of Sumatra. The population of 1.5 million has an average income of 34.6 million Indonesian rupiah (IDR; US$2,940)[12] and consumes 30% of the OECD average per capita energy consumption. Energy supply to Palembang comes increasingly from coal, and the carbon intensity of electricity supply is rising significantly. The large industrial base combined with the carbon intensity of electricity mean that Palembang has a very energy- and carbon-intensive economy.

Energy use in the city has grown by 102% since 2000, and is projected to grow by 129.2% between 2014 and 2025. The current energy bill for the city is IDR10.1 trillion (US$857 million) or 18.7% of GDP. When combined with rising real energy prices, total expenditure on energy is projected to rise 155.1% in 2025. Carbon emissions, which have grown by 143.8% since 2000, are projected to more than double between 2014 and 2025.

12 Calculations at an assumed exchange rate of IDR10,000 = US$0.85

We estimate that Palembang could reduce its carbon emissions by 2025 by 24.1% compared to BAU levels through cost-effective measures. This would require investment of IDR4.8 trillion (US$405.6 million), which would pay for itself within a year through annual savings of IDR5.1 trillion (US$436.8 million). The carbon savings would be distributed among the commercial (1.3%), domestic (23.6%), industry (50.9%), transport (8.6%) and waste (15.5%) sectors. We calculate that reinvesting the returns from these investments in other low-carbon measures would enable a total investment of IDR18.2 trillion (US$1.5 billion) and would deliver emission reductions of 28.3% relative to BAU levels at no net cost to the city.

More detail on the Palembang study can be found in Gouldson, Colenbrander, Sudmant et al. (2014).

Sector Focus: Electricity in Palembang

The provision of reliable, low-carbon electricity substantially expands the opportunities available to cities to reduce emissions. For example, diesel generators are commonly used in Palembang and other Indonesian cities as an alternative to grid supplied electricity. Increasing the reliability and reducing the carbon intensity of grid electricity would allow a wide range of actors to lower their emissions by cutting consumption of diesel fuel. It can therefore be seen as a precursor to other low-carbon investments, and hence we consider it in this case study.

Consumption of grid electricity in Palembang has grown from 65.5 kWh per capita in 2000 to 1,125 kWh per capita in 2014, and is projected to rise to 3,304 kWh per capita by 2025. It is clear that a substantial expansion of electricity generation is required to meet this rapidly growing demand. The new capacity that will be built over the coming decade will determine the carbon intensity of electricity in Indonesia for decades to come. The South Sumatra grid currently generates electricity from coal (48%), natural gas (19%), hydroelectricity (14%), diesel (9%) and geothermal (1%). Under a BAU scenario, the carbon intensity of the grid is would rise from 0.84tCO_2-e/MWh in 2014 to 0.94tCO_2-e/MWh in 2025 as the share of coal electricity in the grid rises to 81%.

Our analysis identifies two possible measures that are cost and carbon effective. Some 1,200MW of geothermal generation capacity could be built instead of coal-fired power plants and 514 MW of existing natural gas generation capacity could be retrofitted with best available technologies on commercially attractive terms. If the proceeds from these measures were reinvested in the electricity sector, a further 2000 MW of geothermal generation capacity could be built at no net cost.

However, delivering geothermal energy on this scale would require overcoming a number of barriers. Geothermal facilities typically require larger capital investment, have longer build times and are subject to greater uncertainty than conventional electricity sources. Geothermal development also requires substantial technical capacity in terms of engineering, geology and environmental planning. This provides an opportunity for strategic knowledge transfer and technical assistance as part of the developed world's climate obligations.

If these barriers can be overcome, the potential benefits of expanding geothermal energy are very significant. We find that, relative to BAU trends, the electricity sector could reduce its emissions by 12.2% through cost-effective investments. This would require investment of IDR35.0 trillion (US$2.9 billion), generating annual savings of IDR2.3 trillion (US$175 million), paying back the investment in 15.2 years and generating annual savings for the lifetime of the measures. Reinvesting the returns from these investments in geothermal generation would provide an extra IDR111 trillion (US$9.5 billion) that would deliver further emissions reductions of 22.7%, relative to BAU trends, in the electricity sector.

Kolkata, India

Kolkata is the third largest and the most densely populated city in India and the 19th largest urban area in the world (Government of West Bengal, Bureau of Applied Economics and Statistics 2009). Its official population of 14.1 million is currently growing at a rate of 6.9% per year (Government of India 2011), but its unofficial population could be much larger. Electricity supply to the city comes largely from the West Bengal grid. Inefficiencies and losses in this grid mean that the electricity consumed in Kolkata has a carbon intensity of 1.52tCO_2-e/MWh, more than double global best practice for low-grade, non-coking coal (IEA 2010).

Average per capita income in Kolkata is 125,109 Indian rupees (INR; US$2,139)[13] and average annual per capita energy consumption is 3.6MWh (7% of the OECD average), but there are stark inequalities within the city. More than a third of Kolkata's population lives in slums, where most people work in informal sectors and a third are unemployed (UN-HABITAT 2003). Even so, electricity demand is growing rapidly. More broadly, we estimate that, under BAU conditions, Kolkata's total energy consumption would rise by 44.1%, expenditure on energy by 111.6% and carbon emissions by 54.0% between 2014 and 2025.

We estimate that Kolkata could reduce its annual carbon emissions by 20.7% by 2025, relative to BAU levels, through cost-effective investments of INR119.3 billion (US$2.0 billion), which would pay for themselves through annual savings of INR 30.4 billion (US$520.7 million) within 3.9 years, and then continue to generate savings for the lifetime of the measures. The carbon savings would be distributed among the commercial (24.7%), domestic (27.6%), industry (15.4%), transport (9.3%), and waste (23.0%) sectors. By reinvesting the returns from these cost-effective options, Kolkata could invest a total of INR205.6 billion (US$3.6 billion) in low-carbon measures and reduce its carbon emissions by 35.9% relative to BAU trends at no net cost to the city.

More detail on the Kolkata study can be found in Gouldson, Kerr, McAnulla et al. (2014).

Sector focus: Waste in Kolkata

The waste sector in Kolkata, as in many developing countries, generates substantial emissions, and BAU trends suggest a steady increase in waste production per capita. When combined with the impacts of population growth, GHG emissions from the waste sector are projected to rise by 37.2% between 2014 and 2025.

Through the introduction of cost-effective new recycling schemes and gasification measures, the city could reduce greenhouse gas emissions by 41.9% relative to BAU levels. This would require investments worth INR13.1 billion (US$224.0 million), generating annual savings of INR1.1 billion (US$18.8 million) and paying back the investment in 11.8 years. Additional investments in energy-from-waste infrastructure (specifically, refuse-derived fuel) could reduce emissions by 61.6% relative to BAU trends at no net cost to the city. This would require a total investment of INR14.6 billion (US$249.7 million) and would generate annual savings of INR1.2 billion (US$20.5 million).

Kolkata's waste sector highlights the importance of evaluating the social and environmental implications of low-carbon measures, as well as the economic case for investment. Poor waste management impacts public health in the city, but also provides important sources of informal employment to some of the most vulnerable populations in the city. Any low-carbon measures should be implemented in ways that capture potential health benefits while protecting these livelihoods, for example through community-led waste management systems.

13 Calculations at an assumed exchange rate of INR100 = US$1.88.

5. DISCUSSION: OPPORTUNITIES AND PRECONDITIONS

5. 1 The scale and significance of the opportunities

On purely economic terms, this comparative analysis indicates that there is a compelling case for climate action in each of the five case study cities. Extensive packages of cost-effective low-carbon investments have been identified in each city that would pay for themselves in less than 4.1 years through reductions in energy bills that would be equivalent to between 1.7% and 9.5% of annual city-scale GDP. The measures would continue to generate economic savings beyond the payback period and over their lifetimes. These same measures would reduce emissions from each city by between 14% and 24% relative to BAU trends by 2025, which equates to real annual carbon savings of between 3.2 and 9.4 $MtCO_2$-e in 2025. Furthermore, if the returns from the cost-effective options could be recovered and reinvested in additional low-carbon measures, these five cities could reduce their emissions by a further 3.2%-21.2% relative to BAU levels in 2025. This equates to another 0.5 to 8.7$MtCO_2$-e.

The scale and the timing of the carbon savings that might be realized in cities worldwide from exploiting economically attractive opportunities are substantial, particularly given the urgent need for early action on climate change. The International Energy Agency (IEA 2013) suggests that, "if action to reduce CO_2 emissions is not taken before 2017, all the allowable CO_2 emissions would be locked-in by energy infrastructure existing at that time". The estimated reductions that are equivalent to a 10-18% reduction in annual global energy-related carbon emissions that could conceivably be achieved if similar cost-effective low-carbon options were available and were exploited in all cities would be a very significant contribution to climate change mitigation.

But our comparative analysis has also shown that in some settings these savings are likely to be overwhelmed by the impacts of ongoing economic and population growth; in order to deliver sustained cuts in carbon emissions, cities would have to explore deeper and possibly more challenging forms of decarbonization, for example through more structural changes in the form and function of the city.

5.2 Preconditions for change

The economic attractiveness of many of the low-carbon options provides a strong incentive for cities to explore the new governance and financing arrangements necessary to exploit these opportunities. In the process, they could create the enabling conditions and momentum for longer-term, transformative change.

A first obvious prerequisite for low-carbon investment in any city is *political commitment*, and this is an area in which a compelling economic case (along with other co-benefits) can be particularly effective. Our studies attracted the attention of decision-makers in all five cities, not only those working on environment and sustainability but also in areas such as economic development that tend to feature more prominently at the heart of urban development policy making. This has helped to build broader commitment to adopting low-carbon development strategies and to mainstream climate targets into urban policy. These impacts underscore the importance of exploring the economic case on a city-by-city basis to mobilize climate action.

A second prerequisite is *finance*. The initial investments needed are large, particularly relative to city budgets. Many of the cost-effective investments could attract private finance – particularly where they can be consolidated into larger opportunities and unlocked through the introduction of new business models such as revolving funds that capture and recycle savings from a large number of small investments, for example in the residential and commercial sectors. Public-sector investment also has an important role to play. Governments are major energy users and investors in infrastructure, and can therefore contribute substantially to climate change mitigation by investing directly in energy-efficient options.

There are multiple ways in which investments in the low carbon economy could be further encouraged. Tax-increment financing, prudential borrowing, and various forms of public-private partnership are emerging in many settings. Many more cities in low- and low middle- income countries could benefit from climate-friendly development assistance and development-friendly climate finance: Lima's BRT system, for example, supported with development assistance from the Inter-American Development Bank, is primarily intended to address congestion, improve air quality and increase mobility, but will also generate substantial carbon savings.

A third prerequisite is an enabling *policy framework*. Although some of the measures identified should be economically attractive enough to secure investments on commercial grounds, others would clearly benefit from policy support in various forms, particularly in the early stages of their deployment in a particular context. Governments can encourage investments by providing supporting incentive and subsidy regimes, for example through feed-in tariffs or tax allowances for renewable generation or through reducing subsidies for fossil fuels such as coal in energy generation or petrol in transportation. They can also encourage investment by creating stability and reducing risk – for example by committing to long-term targets for energy efficiency, by supporting pilot projects that prove the viability of new business models or by acting as the "anchor client" for new initiatives such as district heating schemes implemented by city-scale energy service companies.

Governments can enable different actors to respond to market opportunities and policy signals through education and information provision, for instance by environmental labeling or through support for R&D in different areas of the low-carbon economy. They can also support the building of new capacities to act by promoting community engagement and civic movements or market development and economic networks. Ultimately, governments could mandate investment through regulation – for example through the adoption of tougher vehicle emissions standards or building energy performance standards.

Such policy interventions are likely to be needed both across levels (national, regional and local) and between policy areas (energy, finance, housing, transport and economic development, as well as environment). The prospects for such multi-level, multi-sector policy intervention are likely to be substantially stronger where a compelling economic case has been put forward.

6. CONCLUSIONS

Although clearly we must be careful about extrapolating from a sample of only five cities, our findings offer useful insights into the opportunities for (and the limits of) investment in economically attractive options for low-carbon cities. Given the role that cities are likely to play in the future, such opportunities have major implications for climate change mitigation; economically attractive investments in cities could lead to globally significant reductions in carbon emissions. Reinvesting the returns from such investments up to the point where all investments are cost-neutral would increase carbon savings substantially.

So could the exploitation of these economically attractive low-carbon measures in cities in the short to medium term provide a platform for more transformative change in the longer term? The answer perhaps depends on levels of optimism and the scope for city-level learning.

In an optimistic scenario, some cities exploit these opportunities successfully, and generate both economic and environmental returns from doing so. They also develop appropriate forms of engagement and governance to generate wider social, economic and environmental co-benefits, and through these they increase public interest in, and enthusiasm for, low-carbon development. Institutional capacities are built, new financing arrangements evolve and important lessons are learned over time. Other cities are encouraged to adopt similar models, and the pioneering or front-running cities decarbonize further. In other words, early successes could inspire other cities, breaking the inertia in low-carbon development, and strengthening capacities that enable the front-running cities to explore more ambitious climate mitigation strategies such as structural changes in urban form and function.

In a pessimistic scenario, cities might implement the measures without appropriate forms of engagement and governance. The transition becomes a technocratic exercise that runs the risk of generating social, economic and environmental co-costs and undermining social and political support and momentum for further change. Institutional capacities are built and financing arrangements do emerge, but cities only "cherry pick" the easiest options. The front-running cities lose interest in further change; other cities decide only to invest in low-carbon options where they are economically attractive. Cities maintain their resistance to transformative changes that are likely to be more challenging, so they become locked into what is at best only a marginally decarbonized future. In other words, there is a risk that cities will spend valuable time exploring options that at best are only a temporary or partial response to a pressing global problem, and in the process they crowd out the potential for deeper and more transformative change.

The policy challenge is to find ways of ensuring that the optimistic scenario is realized. For this to happen, policy-makers have to exploit the early stages of the low-carbon transition where there are economically attractive options, while ensuring that they create the conditions for the later stages of transition that could be more challenging. For this to happen, low-carbon transitions would need to be seen as an opportunity rather than a threat, by city-level decision-makers, and they need to be taken from the periphery of urban decision-making and mainstreamed into the key areas of urban policy such as planning, energy, housing, transport and economic development. Appropriate stakeholder engagement and governance capacities need to be established to ensure that the transition is not a technocratic exercise but is 'socially steered' so that choices reflect different social concerns and build public support over time. New financing arrangements and delivery models need to be built, and enabling policies need to be introduced at different scales. Lessons from the front-runners then need to be identified – for example through robust evaluations of early experiences – so that good practice can be rapidly developed within and transferred between cities.

And all of this needs to be done in a way that stimulates a long-term vision of, and a commitment to, a more deeply decarbonized city. If all of this can be achieved, then exploiting economically attractive low-carbon options in cities in the short term could be a major contribution to successful climate change mitigation at the global scale in the longer term.

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APPENDIX

SUMMARIES OF CITY-LEVEL DATA AND PROJECTIONS

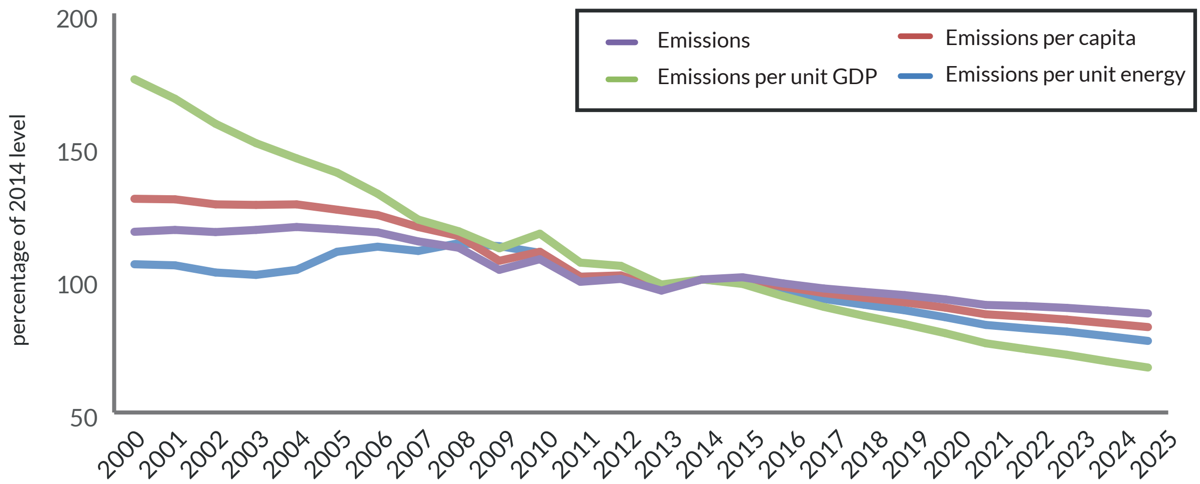
Leeds City Region

Based on Gouldson, Kerr, Topi et al. (2012).

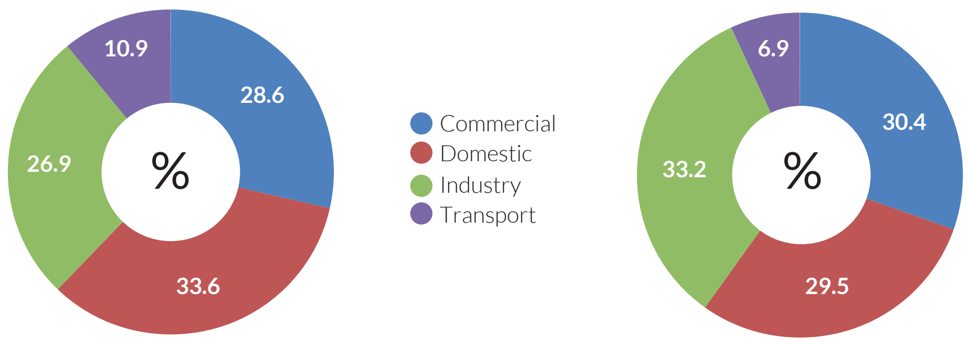
Key economic, energy and carbon indicators for Leeds City Region and the United Kingdom, 2014

UK	GDP per capita (PPP)	US$ 35,722
	Economic growth rate per annum (2003-2012 average)	1.22%
	Energy use per capita (absolute / % of OECD average	3,024kgoe / 75.1%
	Emissions per capita (absolute / % of OECD average	7.9tCO_2-e / 78.2%
Leeds City Region	Population	3.0 million
	Total city GDP	US$ 86.2 billion
	City GDP per capita (PPP)	US$ 26,496
	Energy use per capita	1,889 kgoe
	Energy bill per capita	US$ 3,233
	Energy bill of the city (absolute / % of GDP)	US$ 8.4 billion / 10%
	Carbon intensity of energy use in 2014	0.83 tCO_2/MWh

Source for national data: World Bank Development Indicators. For sources of city-level data see Gouldson, Kerr, Topi et al. (2012).



Historic and projected greenhouse gas emissions per unit of energy, per unit of GDP and per capita in Leeds City Region, 2000-2025, indexed to 2014



Projected shares of economic savings (left) and emissions reductions (right) by sector in Leeds City Region in 2025, with the adoption of the cost-effective bundle of measures

Leeds City Region, continued

The economic case for investment in low-carbon measures at the city scale, Leeds City Region

	Cost-effective scenario	Cost-neutral scenario
Investment needs	US$ 7.67 billion	US$ 18.11 billion
Investment needs as a share of city GDP	8.9%	21.0%
Annual savings	US$ 1.86 billion	US$ 2.49 billion
Payback period	4.1 years	7.3 years
Carbon savings in 2025	3.08 $MtCO_2$-e	4.30 $MtCO_2$-e
Carbon savings in 2025 as a share of the BAU scenario	15.6%	21.8%

League tables of the 10 most cost-effective (left) and carbon-effective (right) low-carbon measures at the city scale for Leeds City Region

Most cost-effective measures per unit of carbon saved[a]			Most carbon-effective measures[b]		
Sector	**Measure**	**Net cost (US$ /tCO_2-e)**	**Sector**	**Measure**	**Emissions saved 2012-2022 $ktCO_2$-e)**
1. Industry	Burners	-1,261	1. Industry	Renewable heat	517
2. Commercial	Photocopiers – energy management	-782	2. Transport	Biofuels	210
3. Commercial	Monitors – energy management	-782	3. Domestic	Reduce household heating by 1˚C	201
4. Commercial	Computers – energy management	-782	4. Domestic	Solid wall insulation	198
5. Commercial	Printers – energy management	-782	5. Commercial	Air source heat pump	155
6. Commercial	Vending machines – energy management	-782	6. Domestic	Biomass boilers with feed-in tariff	154
7. Commercial	Office equipment – most energy efficient monitor (PC only)	-724	7. Transport	Micro hybrid vehicles	145
8. Domestic	Mini-wind turbines (5kW) with feed-in tariff	-715	8. Transport	Full hybrid vehicles	141
9. Commercial	Office equipment – most energy efficient monitor	-683	9. Commercial	Heating – most energy efficient boilers	139
10. Commercial	Turn off lights for 1 extra hour	-661	10. Commercial	Heating – programmable thermostats	136

a Net cost to the city of saving 1 tCO_2-e emissions over the lifetime of the measure. A negative figure indicates a net return.

b Total emissions saved if measures were implemented throughout the period indicated. Note that the periods and calculations reflect those in the original studies, not the adjustments made for the comparative analysis.

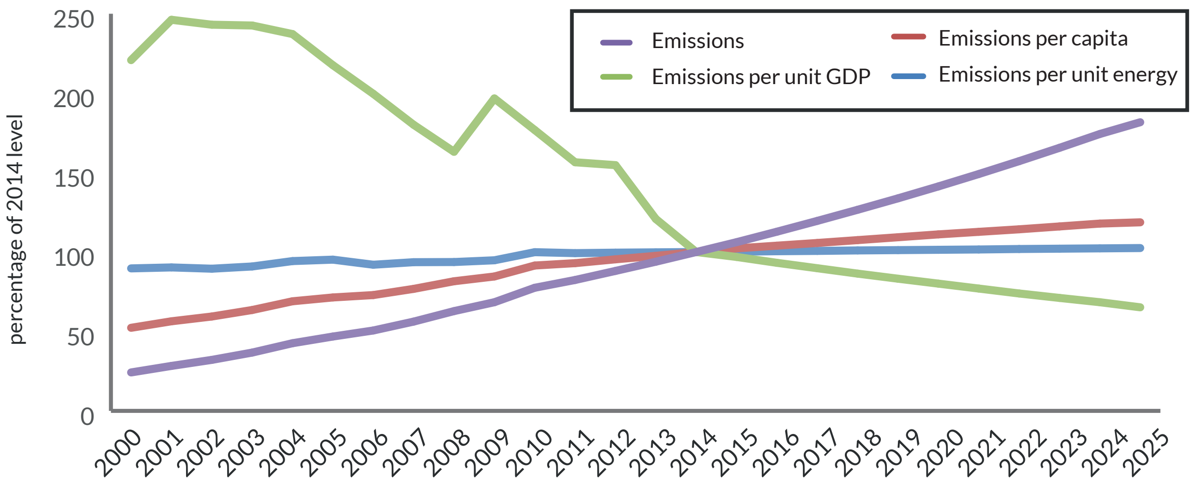
Johor Bahru and Pasir Gudang

Based on Gouldson, Colenbrander, Papargyropoulou, et al. (2014).

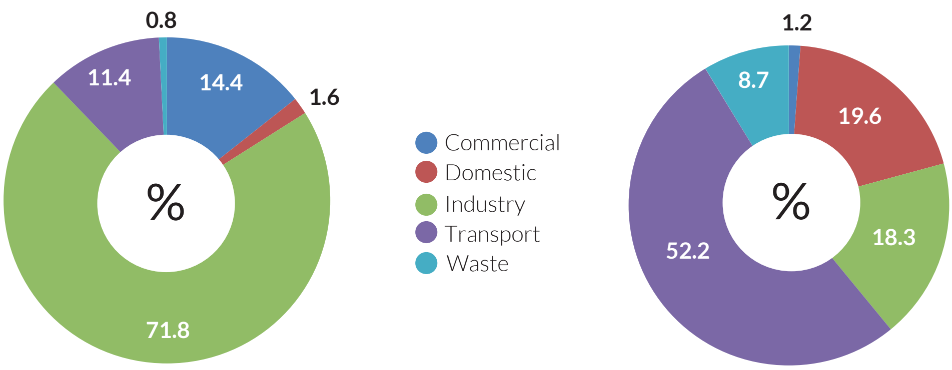
Key economic, energy and carbon indicators for Johor Bahru and Malaysia, 2014

Malaysia	**GDP per capita (PPP)**	**US$ 16,919**
	Economic growth rate per annum (2003-2012 average)	5.37%
	Energy use per capita (absolute / % of OECD average)	2,639kgoe / 65.5%
	Emissions per capita (absolute / % of OECD average)	7.7tCO_2-e / 76.2%
Johor Bahru	Population	1.8 million
	Total city GDP	US$ 26.9 billion
	City GDP per capita (PPP)	US$ 14,790
	Energy use per capita	2,862 kgoe
	Energy bill per capita	US$ 2,733
	Energy bill of the city (absolute / % of GDP)	US$ 4.1 billion / 15.2%
	Carbon intensity of energy use in 2014	2.25 tCO_2/MWh

Source for national data: World Bank Development Indicators. For sources of city-level data see Gouldson, Colenbrander and Paprgyropolou et al. (2014).



Historic and projected greenhouse gas emissions per unit of energy, per unit of GDP and per capita for Johor Bahru, 2000-2025, indexed to 2014



Projected share of economic savings (left) and emissions reductions (right) by sector in Johor Bahru in 2025, with the adoption of the cost-effective bundle of measures

Johor Bahru and Pasir Gudang, continued

The economic case for investment in low carbon measures at the city scale, Johor Bahru and Pasir Gudang

	Cost-effective scenario	Cost-neutral scenario
Investment needs	US$ 1.01 billion	US$ 5.59 billion
Investment needs as a share of city GDP	3.7%	20.8%
Annual savings	US$ 0.77 billion	US$ 0.83 billion
Payback period	1.3 years	6.8 years
Carbon savings in 2025	9.4 $MtCO_2$-e	17.5 $MtCO_2$-e
Carbon savings in 2025 as a share of the BAU scenario	24.2%	45.4%

League tables of the 10 most cost-effective (left) and carbon-effective (right) low-carbon measures at the city scale for Johor Bahru

Most cost-effective measures per unit of carbon saved[a]			Most carbon-effective measures[b]		
Sector	**Measure**	**Net cost (US$ / tCO_2-e)**	**Sector**	**Measure**	**Emissions saved 2014-2025 $ktCO_2$-e)**
1. Commercial	Green building standard 1	- 53,460	1. Industry	Diesel replaced with biodiesel	43,798
2. Commercial	Green building standard 2	- 51,946	2. Industry	B100 (100% biofuel) replaces petroleum products with fuel subsidy	22,050
3. Industry	Rubber – heat recovery	- 3,975	3. Industry	Fuel switching - 50% petroleum products replaced w/ solar PV	21, 357
4. Industry	Fuel switching – 50% petroleum products replaced w/ solar PV electricity w/ feed-in tariff	- 1,756	4. Transport	B100 replaces petroleum products	19,874
5. Transport	Hybrid private cars with current tax relief	- 436	5. Transport	Hybrid private cars with current tax incentive	15,051
6. Industry	Fertiliser – steam reforming (moderate improvements)	- 352	6. Industry	Rubber – adoption of variable speed drive in electric motors	11,232
7. Industry	Fertiliser – steam reforming (large improvements)	- 350	7. Industry	Fuel switching – 50% petroleum systems replaced w/ dual fuel systems	9,725
8. Industry	Petroleum refinery and petrochemical – more efficient pumps	- 339	8. Transport	Euro IV vehicle standards (cars with sales tax relief)	9,169
9. Industry	50% petroleum systems to dual fuel systems	- 335	9. Waste	Energy from waste (comb. heat + power)	8,359
10. Industry	Petroleum refinery and petrochemical – more efficient motors	325	10. Industry	Rubber industry – reduction of excess air in boilers	7,992

Note: Measures in the electricity sector were included in the original study, but have been excluded here.
a Net cost to the city of saving 1 tCO_2-e emissions over the lifetime of the measure. A negative figure indicates a net return.
b Total emissions saved if measures were implemented throughout the period indicated.

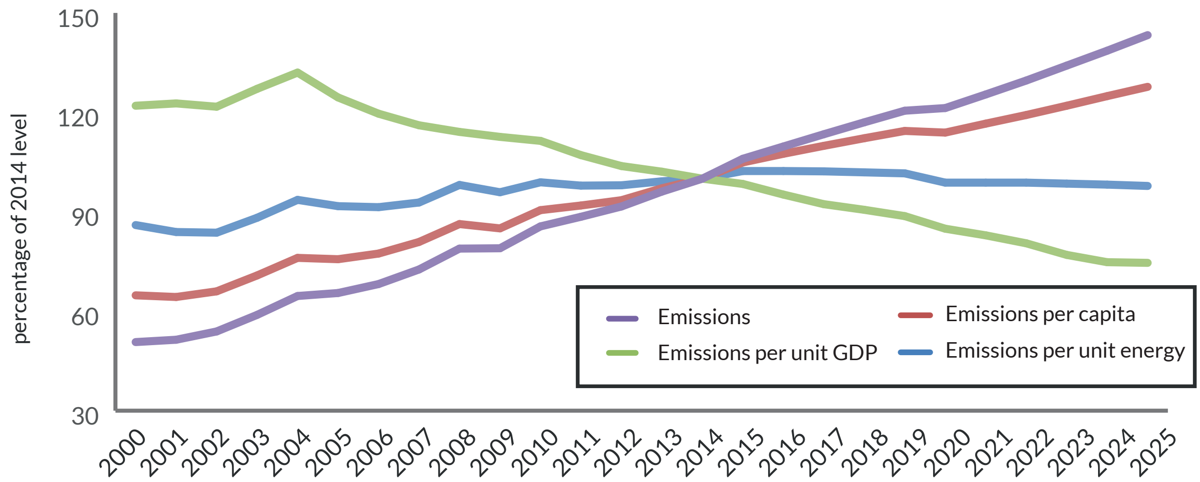
Lima-Callao

Based on Gouldson, McAnulla, Sakai et al (2014).

Key economic, energy and carbon indicators for Lima-Callao, 2014

	GDP per capita (PPP)	US$ 10,765
Peru 1	Economic growth rate per annum (2003-2012 average)	6.03%
	Energy use per capita (absolute / % of OECD average	695kgoe / 17.3%
	Emissions per capita (absolute / % of OECD average	2.0 tCO_2-e / 19.8%
City 2	Population	9.5 million
	Total city GDP	US$ 66.1 billion
	City GDP per capita (PPP)	US$ 6,958
	Energy use per capita	457 kgoe
	Energy bill per capita	US$ 442
	Energy bill of the city (absolute / % of GDP)	US$ 4.2 billion / 6.4%
	Carbon intensity of energy use in 2014 (tCO_2-e/MWh)	0.76 tCO_2/MWh

Source for national data: World Bank Development Indicators. For sources of city-level data see Gouldson, McAnulla, Sakai et al. (2014).



Trends in greenhouse gas emissions per unit of energy, per unit of GDP and per capita in Lima-Callao, 2000-2025, indexed to 2014

Projected share of economic savings (left) and emissions reductions (right) by sector in Lima-Callao in 2025, with the adoption of the cost-effective bundle of measures

Lima-Callao, continued

The economic case for investment in low-carbon measures at the city scale, Lima-Callao

	Cost-effective scenario	Cost-neutral scenario
Investment needs	US$ 5.1	US$ 12.2 billion
Investment needs as a share of city GDP	7.7%	18.4%
Annual savings	US$ 2.12 billion	US$ 2.73 billion
Payback period	2.4 years	4.5 years
Carbon savings in 2025	3.49 $MtCO_2$-e	5.48 $MtCO_2$-e
Carbon savings in 2025 as a share of the BAU scenario	15.4%	24.2%

League tables of the 10 most cost-effective and carbon-effective low-carbon measures at the city scale for Lima-Callao

Most cost-effective measures per unit of carbon saved[a]			Most carbon-effective measures[b]		
Sector	**Measure**	**Net cost (US$ /tCO_2-e)**	**Sector**	**Measure**	**Emissions saved 2015-2030 $ktCO_2$-e)**
1. Residential	Green roofs on semi-detached buildings	14,462	1. Transport	Congestion tolls for petrol and diesel private cars	6,860
2. Residential	Most energy efficient washing machines	8,097	2. Transport	Replacing combis with omnibuses	5,485
3. Residential	Green roofs on apartment buildings	6,460	3. Residential	Incandescent lighting phase out and 50% LED by 2020	4,268
4. Residential	More energy efficient washing machines	4,507	4. Waste	Landfill gas capture for energy generation	3,443
5. Residential	Most energy efficient entertainment appliances	1,283	5. Industry	Electricity conservation in other industrial sectors	3,393
6. Residential	Most energy efficient air conditioners	692	6. Waste	Sludge to energy incinerator	3,276
7. Residential	Most energy efficient refrigerators	321	7. Waste	Waste to electricity – 1000 tons per day	3,079
8. Transport	Diesel taxis replaced with hybrid cars	315	8. Industry	Switch boilers to natural gas	3,063
9. Residential	More energy efficient entertainment appliances	289	9. Transport	Hybrid Scheme - $2000 subsidy for 10% of new cars	2,755
10. Transport	Diesel taxis replaced with CNG cars	187	10. Residential	Incandescent lighting phase out	2,409

Note: Measures in the electricity sector were included in the original study, but have been excluded here.

[a] Net cost to the city of saving 1 tCO_2-e emissions over the lifetime of the measure. A negative figure indicates a net return.

[b] Total emissions saved if measures were implemented throughout the period indicated. Note that the periods and calculations reflect those in the original studies, not the adjustments made for the comparative analysis.

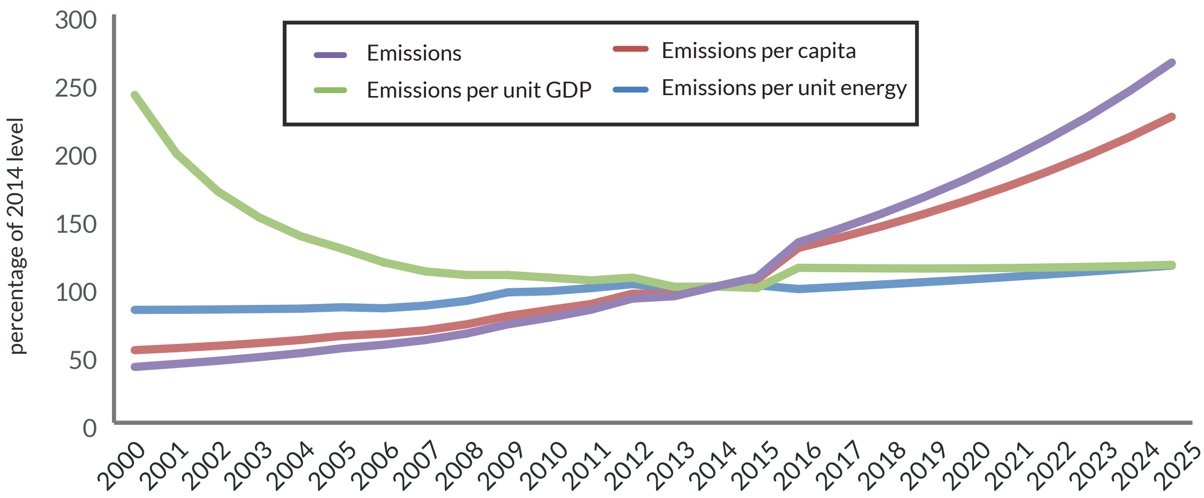
Palembang

Based on Gouldson, Colenbrander, Sudmant et al. (2014).

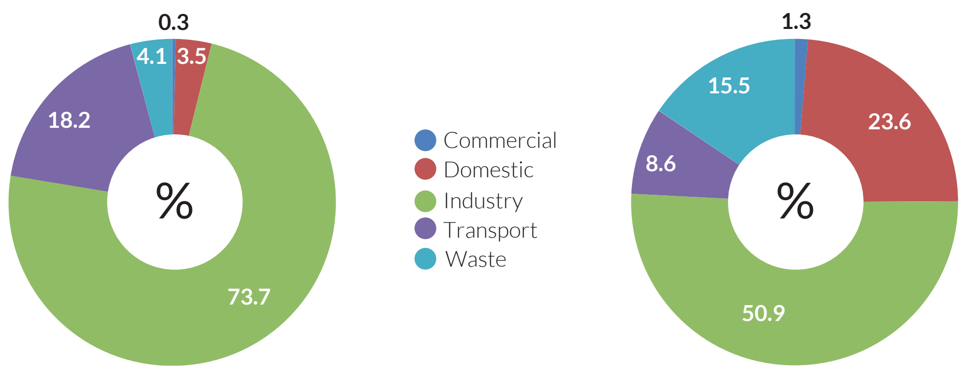
Key economic, energy and carbon indicators for Palembang and Indonesia, 2014

Indonesia	**GDP per capita (PPP)**	**US$ 4,876**
	Economic growth rate per annum (2003-2012 average)	5.74%
	Energy use per capita (absolute / % of OECD average	857kgoe / 21.3%
	Emissions per capita (absolute / % of OECD average	2.0tCO_2-e / 17.8%
Palembang	Population	1.5 million
	Total city GDP	US$ 4.6 billion
	City GDP per capita (PPP)	US$ 2,940
	Energy use per capita	861 kgoe
	Energy bill per capita	US$ 571
	Energy bill of the city (absolute / % of GDP)	US$ 857 million / 18.7%
	Carbon intensity of energy use in 2014	3.41 tCO_2/MWh

Source for national data: World Bank Development Indicators. For sources of city-level data see Gouldson, Colenbrander, Sudmant et al. (2014).



Historic and projected greenhouse gas emissions per unit of energy, per unit of GDP and per capita in Palembang, 2000-2025, indexed to 2014.



Projected share of economic savings (left) and emissions reductions (right) by sector in Palembang in 2025, with the adoption of the cost-effective bundle of measures

Palembang, continued

The economic case for investment in low carbon measures at the city scale for Palembang

	Cost-effective scenario	Cost-neutral scenario
Investment needs	US$ 405.6 million	US$ 1.54 billion
Investment needs as a share of city GDP	8.82%	33.6%
Annual savings	US$ 436.8 million	US$ 467.4 million
Payback period	<1 year	3.3 years
Carbon savings in 2025	3.2 $MtCO_2$-e	3.7 $MtCO_2$-e
Carbon savings in 2025 as a share of the BAU scenario	24.1%	28.3%

League tables of the 10 most cost-effective (left) and carbon-effective (right) low-carbon measures at the city scale for Palembang

Most cost-effective measures per unit of carbon saved[a]			Most carbon-effective measures[b]		
Sector	**Measure**	**Net cost (US$ /tCO_2-e)**	**Sector**	**Measure**	**Emissions saved 2014-2025 $ktCO_2$-e)**
1. Transport	Fuel tax/subsidy reduction of 600 IDR/L	-3,579	1. Industry	Diesel to biodiesel	7,048
2. Transport	Fuel tax/subsidy reduction of 300IDR/L	-2,043	2. Industry	Supplementing diesel boilers with solar water heaters	6,730
3. Commercial	Substituting grid electricity for diesel generators – shopping centres	-1,528	3. Waste	LFG utilisation	33,802
4. Industry	Diesel to dual fuel systems	-1,188	4. Waste	Energy from waste (combined heat and power)	3,414
5. Industry	Replacing diesel generators with solar PV	- 373	5. Industry	Fertiliser – steam reforming (large improvements)	3,166
6. Industry	Petroleum refinery – more efficient pumps	- 314	6. Transport	CNG Bus Rapid Transport system (4x expansion)	2,522
7. Industry	Petroleum refinery – more efficient compressors	- 309	7. Industry	Fertiliser – process integration	2,374
8. Industry	Petroleum refinery – more efficient motors	- 309	8. Domestic	Most energy efficient air conditioners	2,159
9. Industry	Petroleum refinery – more efficient furnaces and boilers	- 308	9. Transport	Bus Rapid Transport system upgrade (4x expansion)	2,139
10. Industry	Petroleum refinery – more efficient heat exchangers	- 300	10. Waste	Energy from waste (electricity recovery)	1,877

Note: Measures in the electricity sector were included in the original study, but have been excluded here.

a Net cost to the city of saving 1 tCO2-e emissions over the lifetime of the measure. A negative figure indicates a net return.

b Total emissions saved if measures were implemented throughout the period indicated.

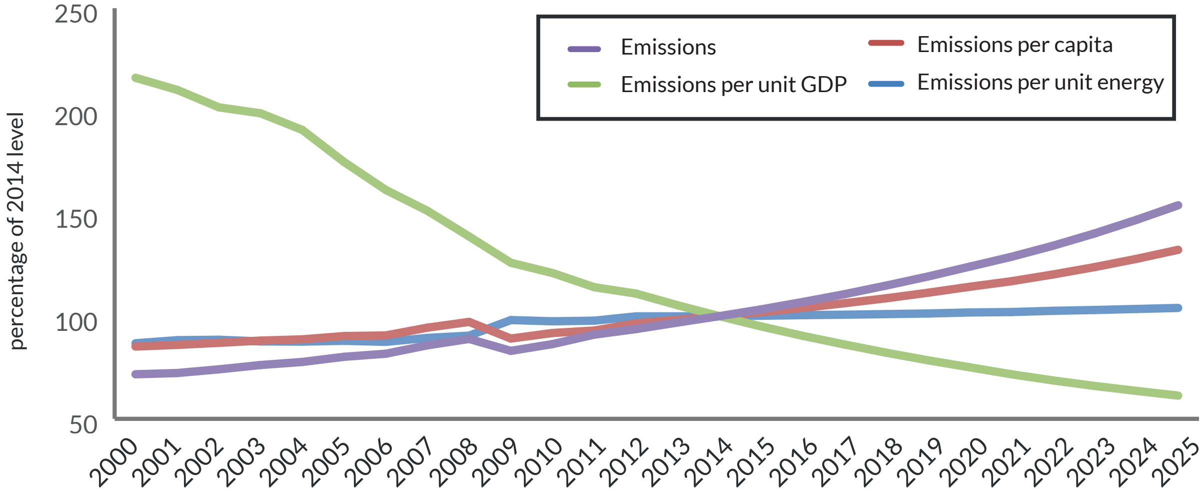
Kolkata

Based on Gouldson, Kerr, McAnulla et al. (2014).

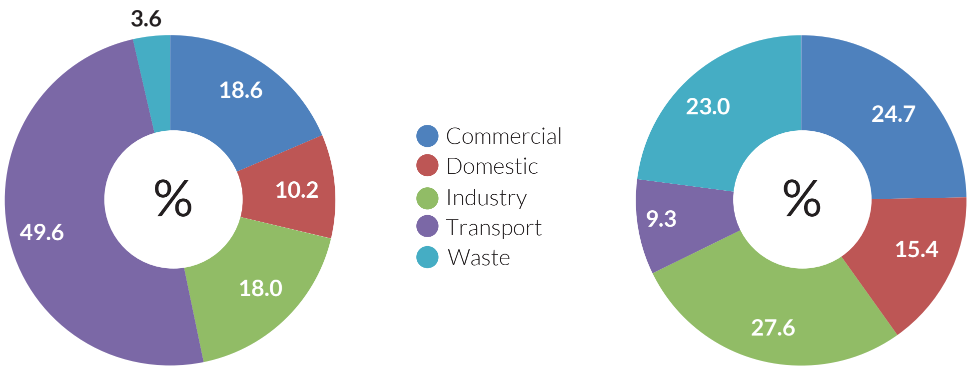
Key economic, energy and carbon indicators for Kolkata and India, 2014

India	GDP per capita (PPP)	US$ 3,870
	Economic growth rate per annum (2003-2012 average)	7.79%
	Energy use per capita (absolute / % of OECD average	614kgoe / 15.2%
	Emissions per capita (absolute / % of OECD average	1.7tCO_2-e / 16.8%
City	Population	14.7 million
	Total GDP	US$ 31.5 billion
	City GDP per capita (PPP)	US$ 2,139
	Energy use per capita	243 kgoe
	Energy bill per capita	US$ 196
	Energy bill of the city (absolute / % of GDP)	US$ 2.9 billion / 9.1%
	Carbon intensity of energy use in 2014 (tCO2-e/MWh)	1.32 tCO_2/MWh

Source for national data: World Bank Development Indicators. For sources of city-level data see Gouldson, Kerr, McAnulla et al. (2014).



Historic and projected greenhouse gas emissions per unit of energy, per unit of GDP and per capita in Kolkata, 2000-2025, indexed to 2014



Projected share of economic savings (left) and emissions reductions (right) by sector in Kolkata in 2025, with the adoption of the cost-effective bundle of measures

Kolkata, continued

The economic case for investment in low-carbon measures at the city scale, Kolkata

	Cost-effective scenario	Cost-neutral scenario
Investment needs	US$ 2.0 billion	US$ 3.6 billion
Investment needs as a share of city GDP	6.3%	11.4%
Annual savings	US$ 520.7 million	US4 573.6 million
Payback period	3.9 years	6.2 years
Carbon savings in 2025	7.6 $MtCO_2$-e	13.5 $MtCO_2$-e
Carbon savings in 2025 as a share of the BAU scenario	20.7%	35.9%

League tables of the 10 most cost-effective (left) and carbon-effective (right) low-carbon measures at the city scale for Kolkata

Most cost-effective measures per unit of carbon saved[a]			Most carbon-effective measures[b]		
Sector	Measure	Net cost (US$ /tCO_2-e)	Sector	Measure	Emissions saved 2014-2025 $ktCO_2$-e)
1. Transport	Parking demand management	-1,380	1. Commercial	Green building standard 2 (100% of new buildings)	6,768
2. Industry	Metals and fabrication – waste heat recovery (oil-fired melting)	-383	2. Domestic	Most energy-efficient air conditioners	6,003
3. Industry	Paper – pressurised head box	-372	3. Domestic	Retrofitting fibreglass urethane (20% of existing households)	4,989
4. Industry	Metals and fabrication – wood gasifier (oil-fired melting)	-344	4. Domestic	More energy-efficient air conditioners	4,560
5. Industry	Metals and fabrication – waste heat recovery (coke-fired melting)	-279	5. Commercial	Most energy-efficient air conditioners	3,688
6. Transport	Commercial vehicle efficiency standards	-276	6. Domestic	Most energy-efficient entertainment appliances	3,529
7. Industry	Chemicals – insulation of cyclone system in spray dryers	-250	7. Commercial	Turning off lights	3,519
8. Industry	Metals and fabrication – induction furnace for melting	-249	8. Commercial	Green building standard 1 (100% of new buildings)	3,384
9. Industry	Metals and fabrication – wood gasifier (coke-fired melting)	-248	9. Commercial	Green building standard 2 (50% of new buildings)	3,384
10. Industry	Chemicals – installation of exhaust gas heat recovery system in spray dryers	-238	10. Domestic	More energy-efficient entertainment appliances	2,937

Note: Measures in the electricity sector were included in the original study, but have been excluded here.

[a] Net cost to the city of saving 1 tCO_2-e emissions over the lifetime of the measure. A negative figure indicates a net return.

[b] Total emissions saved if measures were implemented throughout the period indicated.

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The Global Commission on the Economy and Climate is a major new international initiative to examine the economic benefits and costs of acting on climate change. Chaired by former President of Mexico Felipe Calderón, the Commission comprises former heads of government and finance ministers, and leaders in the fields of economics, business and finance.

The New Climate Economy (NCE) is the Commission's flagship project. It provides independent and authoritative evidence on the relationship between actions which can strengthen economic performance and those which reduce the risk of climate change. It will report in September 2014 in advance of the UN Climate Summit. It aims to influence global debate about the future of economic growth and climate action.

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