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The economic case for low-carbon development in rapidly growing developing world cities: A case study of Palembang, Indonesia

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H I G H L I G H T S

- We evaluate the economic case for low carbon investment in a developing world city.
- Cost-effective measures could reduce emissions by 24.1% relative to BAU levels.
- These pay for themselves in < 1 year and generate savings throughout their lifetime.
- Further savings come from reduced expenditure on energy infrastructure, subsidies.
- Limitations on climate action seem to be political/institutional – not economic.

A R T I C L E I N F O

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A B S T R A C T

Where costs or risks are higher, evidence is lacking or supporting institutions are less developed, policymakers can struggle to make the case for low-carbon investment. This is especially the case in developing world cities where decision-makers struggle to keep up with the pace and scale of change. Focusing on Palembang in Indonesia, this paper considers the economic case for proactive investment in low-carbon development. We find that a rapidly growing industrial city in a developing country can reduce emissions by 24.1% in 2025, relative to business as usual levels, with investments of USD405.6 million that would reduce energy expenditure in the city by USD436.8 million. Emissions from the regional grid could be reduced by 12.2% in 2025, relative to business as usual trends, with investments of USD2.9 billion that would generate annual savings of USD175 million. These estimates understate the savings from reduced expenditure on energy subsidies and energy infrastructure. The compelling economic case for mainstreaming climate mitigation in this developing country city suggests that the constraints on climate action can be political and institutional rather than economic. There is therefore a need for more effective energy governance to drive the transition to a low-carbon economy.

1. Introduction

1.1. The need for investment in low-carbon development

With historical deficits in infrastructure investment, and rapid population and economic growth, developing countries need to invest heavily in modern energy systems in order to meet human development goals. Global energy demand is consequently expected to increase by a third between 2012 and 2035, with 90% of this growth coming from emerging economies (IEA, 2014).

Since modern energy is predominately derived from fossil fuels, expanding supply typically entails increasing greenhouse gas emissions (Halsnaes and Garg, 2011). Without radical changes to global energy trends by 2017, the IEA (2013a) predicts that we will be 'locked in' to a 2 °C temperature rise by 2100. In other words, severe climate change will slow and possibly reverse recent development gains unless both developed and developing countries begin to identify and pursue low-carbon development paths. This will involve decarbonising new investments in the power sector, as well as making investments in energy efficiency, public transport and other low-carbon measures.

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Many cities, and particularly those in the developing world, lack the technical, financial and institutional capacities needed to shift to less carbon-intensive trajectories (IPCC, 2014). In many settings low-carbon energy has been more expensive than high-carbon energy (Halsnaes and Garg, 2011; Jacobs, 2012) and faces higher risks due to, among other things, relative capital intensity, technical unfamiliarity and complicated permit processes (Schmidt, 2014). Lack of awareness, confidence or technical skills also pose a major barrier to low-carbon investment in developing countries (Kennedy and Basu, 2013). Policymakers in this context find it difficult to manage a transition to low-carbon energy, particularly in light of the pace and scale of change. High-carbon development may therefore be less a result of decisions as of non-decisions.

This paper aims to explore the existence and extent of economically attractive opportunities for climate action in cities in a developing country context. We argue that the presence of such a case is often a necessary (but not sufficient) condition for change. An economic case could help to build the political commitment and strengthen the institutional capacities required to make the governance arrangements and investments necessary for cities to start the transition towards lower-carbon development paths.

1.2. Cities as climate actors

Cities are currently responsible for 67%–76% of energy use and 71%–76% of energy-related CO_2 emissions (IPCC, 2014). Both the total and share of emissions from cities can be expected to increase substantially, as the urban population is expected to increase by three billion people by 2050 (UNDESA, 2013; WHO, 2014; IPCC, 2014). 90% of the projected growth in the world's urban population will take place in developing countries, where the urban population is expanding by 1.2 million people per week (WHO, 2014). Developing world cities must therefore be at the forefront of climate change mitigation efforts.

The carbon footprint of individual cities depends on, among other factors, income level and lifestyle, socio-economic development, urban spatial structure and transportation systems, energy technologies and local climate factors (Phdungsilp, 2009). Municipal government have the capacity to promote more efficient urban forms through the issue of planning permits, design of transport infrastructure and enforcement of energy regulation (Phdungsilp, 2009; Zusman et al., 2012). This could help rapidly growing cities avoid ‘lock in’ to higher cost, higher carbon development paths. Many cities have already implemented energy efficiency, fuel switching and waste management schemes to generate revenue from the sale of Certified Emission Reductions (CERs) as part of the Clean Development Mechanism (Dhakal, 2008). Focusing on cities therefore both targets major sources of carbon emissions and empowers new actors in the fight against climate change.

1.3. The Southeast Asian context

Southeast Asia exemplifies many of the developing world's energy challenges. Energy poverty remains widespread, with individual energy consumption at approximately half the global average (IEA, 2013b). The low levels of energy use, combined with population growth and rapid industrialisation, mean that energy demand is projected to increase by over 80% over the next twenty years, “a rise equivalent to current demand in Japan” (IEA, 2013b, p. 11). Meanwhile, the population and infrastructure of Southeast Asia are heavily concentrated in low-lying coastal and deltaic zones, meaning that they are extremely vulnerable to sea level rise. Climate change is also projected to cause severe water stress, food insecurity and increases in cholera, diarrhoea and other water-borne diseases across the region by 2020 (Cruz et al., 2007).

Economic growth, energy use and emissions (excluding land use change) from Southeast Asia are concentrated in cities. Although less than half the population live in cities (UNESCAP, 2013), urban economies contribute around 80% of national GDP to Asian economies (Muller, 2013). Southeast Asian cities are expected to expand by nearly 300 million people between 2007 and 2050 (Gubry, 2008), and second-tier cities will have to absorb most of this growth (Phdungsilp, 2009). In much of Southeast Asia, energy consumption correlates more strongly to urbanisation than overall economic growth because living in cities increases energy demand due to increased modernity, industrialisation and ‘heat island’ effects (Jafari et al., 2012), whereby urban air temperatures are higher than those of rural areas as cooling vegetation is replaced by heat-absorbing infrastructure. As Puppim de Oliveira (2013, p. 8) writes, “successful mitigation in these rapidly developing cities is key to achieving worldwide stabilisation in the emissions of greenhouse gases.”

1.4. The Indonesian context

Indonesia is the third largest greenhouse gas emitter in the world, predominately from forest and peatland fires (Agung et al., 2014). Energy consumption in Indonesia remains relatively low at 0.85 toe per capita – compared to the average of 4.28 in OECD countries, 1.7 in China or 0.67 in Africa (World Bank, 2014a) – and so, accordingly, do energy-related greenhouse gas emissions. Per capita emissions in Indonesia are only 40% of the world average and 18% of the OECD average (UNDESA, 2014). However, Indonesia is rapidly expanding its fossil fuel-based electricity supply to meet its human development goals, so energy-related emissions per capita are projected to rise rapidly. Since Indonesia has the fourth largest population in the world at 249.9 million (World Bank, 2014b), this increase will be globally significant. Meanwhile, the high population density on an archipelago nation makes the country highly vulnerable to climate change; 41 million Indonesians live less than 10 m above sea level (Bell, 2012).

The broader context on energy and climate in Indonesia is directly relevant to cities. Currently, 51% (125.9 million) of the Indonesian population lives in cities (World Bank, 2014d). Urbanisation is progressing at the rapid rate of 2.45% per annum (CIA, 2014b), which meant that Indonesian cities expanded by 34.1 million people between 2000 and 2010 (World Bank, 2012, p. 10). This places heavy pressure on urban planning and service provision. Energy consumption per capita in Indonesia is much higher in urban than rural areas, although there are significant inequalities within cities with respect to energy access and use. The inequality within cities also means that the impacts of climate change will be disproportionately borne by the urban poor. Poorer communities are more likely to live on marginal lands that are more vulnerable to droughts, flooding and landslides (UNDP, 2007). Their rudimentary sanitary systems are also more easily overwhelmed by heavy rainfall, so climate change will increase exposure to water-borne diseases such as cholera and diarrhoea (UNDP, 2007). Indonesian cities such as Palembang are therefore increasingly both contributing and vulnerable to climate change.

1.5. Palembang as a case study

Palembang is the capital of the state of South Sumatra. It has a population of 1.5 million (UN-Data, 2011) and GDP per capita of USD 2940 (IFC, 2013). It is a major port and industrial hub in Indonesia, with significant industries including textiles and apparel, wood and paper products, chemicals and pharmaceuticals, rubber and plastic products, fabricated metals, and machinery.

Despite economic growth rates of 6%–7% (Putra, 2012, p. 4), Palembang faces substantial social and economic challenges. Industrialisation combined with a growing vehicle fleet mean that air pollution and congestion pose severe problems. Electricity consumption in Palembang in 2014 remains low at 1125 kWh per capita, or less than 20% of that in neighbouring Malaysia. The city has also implemented a national fuel switching initiative, converting the domestic sector from kerosene to LPG in 2007 (Budy and Arofat, 2011).

Palembang has substantial scope to transition on to more energy and carbon-efficient trajectories. If the city achieves its target growth rate of 6% a year, half of the urban economy that will exist in 2025 has not been built yet. Moreover, there is national and international support for its goals. Palembang has been selected by the Indonesian Ministry of Transport as one of three cities to showcase sustainable transport options. The city council is collaborating with German Federal Enterprise for International Cooperation (GIZ) on a clean air initiative and with the Japan International Cooperation Agency (JICA) on a solid waste management programme. The city council is therefore already seeking to mainstream environmental issues into development planning.

This paper evaluates the extent of the economic case for low-carbon energy investment in Palembang to determine whether there is potential to achieve climate targets – such as increasing energy efficiency and reducing the carbon intensity of energy consumed – in a cost-effective way. While an economic case for climate action does not independently justify investment, it should prompt decision-makers to re-evaluate the assumptions that climate action entails opportunity costs and that low-carbon goals are not compatible with development goals.

The remainder of this paper is structured as follows. Section 2 presents the methods employed for data collection and analysis. Section 3 provides the empirical results. Section 4 discusses the implications and limitations of the findings, while the conclusions are presented in Section 5.

2. Methods, data sources and assumptions

In this paper, we explore the scope for economically attractive investments in climate mitigation at the city scale. We do this by presenting a bottom-up assessment of the costs, returns and carbon savings of a wide range of low-carbon measures. The impacts of these measures are compared against business as usual (BAU) modes of development for the city's energy use, energy bills and carbon emissions to 2025. The findings are drawn together to determine the economic case for, and mitigation potential of, low-carbon investment in the city. This paper builds on the research conducted as part of the Climate Smart Cities programme (Gouldson et al., 2014) in collaboration with the Indonesian Ministry of Transport.

We focus on the direct, private economic costs and benefits of different low-carbon measures in each city. We are acutely aware that many such measures have potentially significant co-costs and co-benefits, and important distributional consequences and environmental impacts, although we do not formally consider these in the quantitative analysis presented here. This is not meant to downplay the significance of developing a wider social case for the low-carbon transition. However, our aim is to explore whether there is a direct economic case for investment in low-carbon transitions in cities, as this is often the pre-requisite for considering potential investments and their wider impacts.

The study considers emissions from the consumption of fuels (i.e. Scope 1 emissions) and purchased electricity (i.e. Scope 2 emissions). Industrial process emissions, which typically fall into Scope 1, had to be excluded because data were not available. We assume that BAU trends can continue to 2025 without accounting for, for example, the likely impacts of increasing congestion on growing vehicle ownership. Given the focus of the study on economic valuation of low-carbon measures, we have not considered the impact of significant changes in land use planning or the spatial distribution of activities within the city. Such modifications to urban form and function are outside the scope of this study.

2.1. Baseline analysis

We collected data that enabled us to understand the levels and composition of energy supply to, and demand in, Palembang. We considered the housing, commercial buildings, transport, industry and waste sectors within the city, and also evaluated the electricity grid that serves the state of Sumatra.

Data on state-level electricity consumption between 2000 and 2012 were obtained from Indonesia's national electricity utility, Perusahaan Listrik Negara (PLN, 2009, 2010, 2011, 2012). City-level data were available for 2012 from Kota Palembang (2012), and we assumed that the share of electricity consumed by Palembang relative to the rest of South Sumatra was constant. Data on other industrial energy use in 2010 were obtained from University of Sriwijaya (2013, pp. 33–38,43–55), and held constant in the absence of data on historical consumption or planned investments. The number of vehicles in Palembang in 2008–2010 was obtained from the University of Sriwijaya (2013, pp. 78, 83, 84), and back-cast using state-level vehicle growth rates from the Indonesian Department of Statistics (Badan Pusat Statistik, 2013, p. 394). Data on the average fuel efficiency of Indonesian vehicles were collected from Silitonga (2011, p. 5214). Data on waste generation in the city were obtained from the University of Sriwijaya (2013, p. 60). Waste composition, average waste collection rate, recycling rate and open burning rate were based on data provided by Connor et al. (2012), Medina (2008), and Chaerul et al. (2013).

Nominal energy prices for 2000–2013 were obtained from Badan Pusat Statistik (2013, p. 416), PLN (2009, 2010, 2011, 2012, pp. 10, 52) and the World Bank (2014c). All energy prices were based on those paid by the consumer, and consequently excluded the additional costs incurred by the government in the form of subsidies. Nominal prices were converted into real prices at 2013 levels using the IMF Monthly Consumer Price Index (IMF, 2014).

We developed BAU baselines for each sector, and for the city as a whole, based on the continuation of these trends through to 2025. These baselines were shaped by, for example, a national economic growth rate of 6.4% (IFC, 2013), a city population growth rate of 2.27% (Badan Pusat Statistik Kota Palembang, 2007) and the changing carbon intensity of the Sumatran electricity grid, which we calculated using data from PLN (2009, 2010, 2011, 2012). We modelled a 3% annual increase in real energy prices between 2014 and 2025, which is conservative compared with historical increases for diesel, gasoline and residential/social electricity prices between 2000 and 2013. The resulting baselines allowed us to predict future levels and forms of energy supply and demand, as well as future energy bills and carbon footprints. We compared all future activities against these baselines.

2.2. Identification and assessment of measures

We compiled a long list of the energy efficiency, renewable energy and low-carbon measures that could potentially be deployed in the city, including both technological and behavioural measures. These were derived from the academic and grey literature. The long list was revised through stakeholder consultations to add locally specific measures and remove any options that are not applicable in the Indonesian context. The resulting short list was not necessarily exhaustive – some measures may have been overlooked, while others may not have been included in the analysis due to the absence of data on their performance.

Again drawing on extensive literature reviews and stakeholder consultations, we conducted a cost-benefit analysis of each measure on the shortlist in order to determine its economic feasibility and impact on carbon emissions. We collected data on the capital, operating and maintenance costs of each low-carbon measure and the high-carbon alternative, and then calculated the marginal or extra costs associated with the low-carbon option. We then conducted a realistic assessment of the likely energy consumption and carbon emissions from each measure over its lifetime, taking into account installation and performance gaps, compared with the high-carbon option. This allowed us to determine potential economic and carbon savings. The data sources and assumptions are detailed in Appendix A. As each measure could be in place for many years, we incorporated the changing carbon intensities of energy use, an average annual rise of 3% in real energy prices and a standard real interest or discount rate of 5%. The Central Bank's nominal discount rate was 6.37% as of 2010 (CIA, 2014a), and the private nominal interest rate is 7.5% (Bank Sentral Republik Indonesia, 2014). Our real discount rate is therefore conservative, considering Indonesia's historically high inflation rates (Badan Pusat Statistik, 2013). The economic and carbon savings for each measure – if deployed independently – are detailed in Table 1 and Appendix B.

This analysis was conducted in early 2014 when oil prices exceeded USD100 per barrel. The dramatic fall in oil prices in late 2014 and early 2015 could reasonably be expected to affect the economic case for low-carbon investment. To assess this impact, we also assessed the economic case for low-carbon measures in the industry and transport sectors with a real oil price of USD60 per barrel in 2015, and a subsequent price increase of 3% per year. These two sectors are the largest consumers of oil in the city and therefore the most vulnerable to market volatility. Evaluating the economics of low-carbon options in these sectors with such a cautious estimate of future oil prices is a robust test of the sensitivity of our findings.

2.3. Assessment of the scope for deployment

We evaluated the potential scope for deploying each of the measures in the various sectors in Palembang in the period to 2025 based on stakeholder consultations. We calculated deployment not only for sectors as a whole, but also for sub-sectors: for example, we assessed the scope for an option to be adopted in a particular industry or income bracket. This allowed us to develop realistic and ambitious rates of deployment, with realistic rates being based on readily achievable levels of uptake and ambitious rates assuming levels of deployment that could be achieved with supporting policies and favourable conditions in place. These assessments took into account the life spans and replacement rates of existing measures that could be replaced with more energy or carbon efficient alternatives, and also rates of change and growth in the relevant sectors of the city. The estimated scopes for deployment were subject to participatory review in expert workshops to ensure that they were as realistic as possible. The two rates of deployment (where applicable) are detailed for each measure in Appendix A.

The workshops were organised and hosted by the Indonesian Ministry of Transport. Participants included representatives of the Ministries of Energy and Mineral Resources, Environment, Housing, Industry, Public Works and Transport, as well as representatives of the City Council of Palembang and the Secretariat of the National Action Plan for Greenhouse Gas Emission Reduction. Two sets of workshops were held, with a total of seventeen participants.

2.4. Aggregation of findings

We drew together the results from our assessment of the performance of each measure, and the scope for deploying each measure, to develop aggregations of the potential impact across the different sectors and the city as a whole. This allowed us to understand overall investment needs and paybacks, as well as the effect on energy supply and demand in the different sectors in the city. Some of the measures interact with each other so that their performance will depend on whether/to what extent another option is also adopted. For example, the emission reductions from most measures depend on the carbon intensity of electricity supply, and this in turn depends on whether various low-carbon measures have been adopted in the electricity supply sector. Similarly, the carbon savings from more efficient air conditioners depend on whether there are green building standards in place. When we were determining the potential savings across a sector or across the city economy, we calculated the effect of each measure on the potential energy savings of other measures to develop realistic assessment of their combined impacts. For example, any electricity savings from efficiency improvements in the housing sector are deducted from the emission reductions associated with investments that would reduce the carbon intensity of the grid.

In many cases, a single measure was considered under varying policy conditions: for example, solar photovoltaic panels with and without feed-in tariffs or waste infrastructure with high and low gate fees. When calculating the aggregated saving potential, the cost-effective options that require the least enabling policies have been included unless these policies are already established at scale. Therefore, the total investment needs, energy savings and payback periods reflect those of solar photovoltaic (PV) panels without feed-in tariffs and waste infrastructure with low gate fees. The final results were reviewed and revised by representatives of the Ministries of Energy and Mineral Resources, Environment and Transport.

Table 1
League table of low carbon measures for the electricity sector supplying Palembang.

Rank	Measure	Carbon savings (ktCO_2-e)	Economic savings (USD/tCO_2-e)	Total economic savings (USD)
1	Geothermal replacing new coal-fired power plants (1000 MW)	37,291	8	298,328
2	Natural gas retrofit with best available technologies (514 MW)	1,233	62	76,446
3	Geothermal replacing new coal-fired power plants (2000 MW)	74,583	−2	−149,166
4	Solar PV replacing natural gas (1200 MW)	6092	−87	−530,004
5	Solar PV replacing coal (1200 MW)	13,127	−49	−643,233
6	Coal retrofit (2185 MW)	2760	−915	−2,525,400
7	Coal with best available technologies (3673 MW)	4639	−915	−4,244,685

3. Results

3.1. Business as usual trends

In 2014, we find that Palembang consumed 15.6 TWh of energy at a cost of IDR10.08 trillion (USD857.2 million), which is equivalent to 18.7% of the city's annual GDP. BAU trends will lead total energy consumption to rise by 129.2% to a forecast level of 35.9 TWh in 2025. When combined with increasing real energy prices, this will lead total energy expenditure to increase by 155.1% to a forecast level of IDR25.73 trillion (USD2.19 billion) in 2025.

The emissions intensity of electricity generation in Sumatra is projected to increase slightly over the coming decade, from 0.84tCO_2-e/MWh in 2014 to 0.97tCO_2-e/MWh in 2025, as several coal-fired power plant come online. The increase in emissions intensity will be smaller if the national electricity utility, PLN, achieves its ambitious geothermal production targets. The increased carbon intensity of energy combined with an expansion of industry is likely to offset any anticipated gains in energy efficiency, so emissions produced per unit of GDP are projected to remain roughly constant from 2014 to 2025. With rapid growth of energy consumption and GDP anticipated, emissions attributed to the city are forecast to increase by 164.6% in a BAU scenario, from 4.6MtCO_2-e in 2014 to a forecast level of 12.3MtCO_2-e in 2025.

Trends at the city scale can be very different to individual experiences of development. We find that energy use per capita in Palembang has more than doubled between 2000 and 2014, and will nearly double again between 2014 and 2025. Over 80% of this increase comes from industry and transport (particularly an expansion of the vehicle fleet), meaning that the poorest populations in the city will not capture many of the benefits associated with increased energy consumption. Growth in energy bills and emissions per capita will outstrip increases in energy use due to rising real energy prices and increasing carbon intensity of electricity (see Fig. 1).

3.2. Economic opportunities to decarbonise electricity

Palembang is served by the Sumatran electricity grid. As of 2014, 48% of electricity into the Sumatran grid is generated from coal, 19% from natural gas, 14% from hydroelectric, 9% from diesel and 1% from geothermal energy.

Electricity consumption rates in Palembang are expected to nearly triple to 3305 kWh per capita in 2025. Combined with population growth, this leads electricity consumption to increase from 1.8 TWh in 2014 to 6.1 TWh in 2025. This will require a dramatic expansion of electricity supply, offering a substantial opportunity to integrate low-carbon sources of energy into the Sumatran grid. Investments in the electricity sector affect the whole grid, offering immense carbon savings across the island of Sumatra although only a small proportion of these would be realised in the city of Palembang.

We find that BAU trends in carbon emissions from the Sumatran electricity sector could be reduced by 12.2% in 2025 with cost-effective measures that would more than pay for themselves on commercial terms over their lifetime. In the city of Palembang, these investments would reduce energy consumption by 875.8 GWh and carbon emissions by 2.5%. The relevant measures are installing 1000 MW of geothermal and retrofitting 514 MW of natural gas-fired power plants with best available technologies. This would require additional investment of IDR35.0 trillion (USD2.9 billion), generating annual savings of IDR2.3 trillion (USD175 million) and paying back the investment in 15.2 years. If the returns from these cost-effective investments were re-invested in 2000 MW of geothermal generation, the BAU level of emissions from the Sumatran electricity sector in 2025 could be reduced by 34.9% and from Palembang by 3.7%. This measure would require IDR111 trillion (USD9.5 billion), generating annual savings of IDR6.5 trillion (USD552 million) and paying back the investment in 17.1 years. To put these investments in context, Indonesia currently needs to spend an estimated USD6 billion per year and expand capacity by 5000 MW annually in order to meet growing electricity demand. The additional capital costs required to generate low-carbon electricity are therefore significant, but not overwhelming in light of their relatively high economic returns in the medium-term.

Although these results indicate that geothermal power could be economically attractive in Indonesia, investment has been limited by a combination of technical risk, higher capital costs, unfavourable tender processes and low electricity prices (Smith, 2012). By comparison, coal is indirectly subsidised through the Domestic Market Obligation policy that requires coal companies to sell at a government-specified, subsidised rate to PLN (Chattopadhyay and Jha, 2014).

We also evaluated the economics of installing 1200 MW of solar photovoltaic (PV) panels, retrofitting 2185 MW of coal-fired power plants with best available technologies (BAT) or constructing 3673 MW of planned new coal-fired power plants with BAT. The additional investment required and the resulting energy savings did not prove economically attractive relative to the

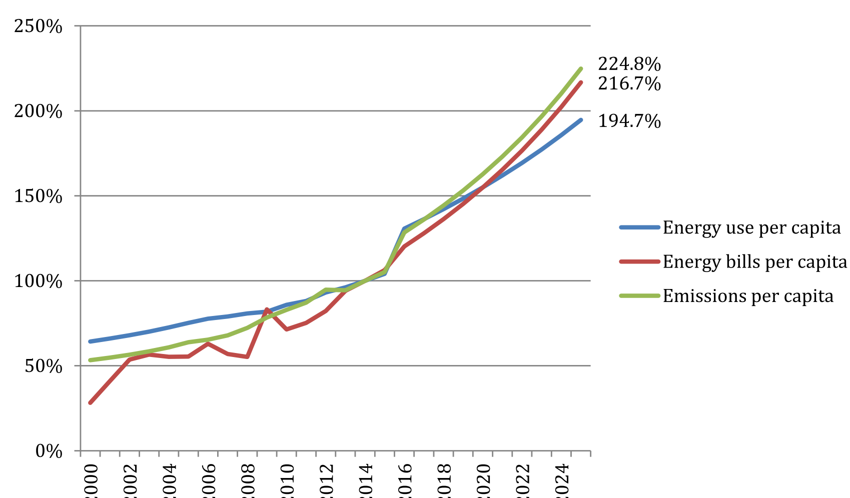

Fig. 1. Trends in per capita energy consumption, energy bills and emissions in the city of Palembang between 2000 and 2025.

baseline scenario. We find that large-scale solar PV in Sumatra would be economically attractive with a carbon price of USD20, but would only be competitive with coal at a carbon price of USD50 (see Table 1).

Our analysis of the electricity sector focuses on opportunities for large-scale investment to supply the Sumatran grid. We consider small-scale renewable technologies, such as rooftop solar PV and solar water heating, in our analysis of low-carbon options at the city scale. Low wind speeds in Indonesia mean that there is limited potential for large-scale wind energy generation: only small (< 10 kW) and medium (< 100 kW) generators would be appropriate (Hasan et al., 2012). These have limited potential relative to solar, hydro or geothermal energy. Sumatra has biomass electricity potential of 40–50 GWh per year, which is expanding quickly with the development of the Indonesian palm oil industry (Conrad and Prasetyaning, 2014; Singh and Setiawan, 2013). While the Indonesian Government has adopted a goal of 5% electricity generation from biomass by 2025 (Nasution et al., 2014), significant concerns surround the palm oil industry including impacts on biodiversity, human rights, land ownership and emissions from deforestation and degradation of peatland (Fitzherbert et al., 2008; Colchester et al., 2006; Wakker et al., 2005). In Indonesia palm oil plantations have converted more than 40 million ha of land, or approximately 30% of forest cover (Wicke et al., 2011). After extensive consultation with stakeholders in Indonesia, we did not evaluate biomass power on the basis that we could not obtain accurate data on the cost, availability or upstream carbon footprint of this measure.

3.3. Economic opportunities to decarbonise the city

We find that the city of Palembang could reduce its carbon emissions by 2025 by 24.1% (relative to BAU levels) through cost-effective investments within the city. Realising these emission reductions would require an investment of IDR4.77 trillion (USD405.6 million), which is a very substantial sum at 8.8% of the city's annual GDP in 2014. However, these measures would reduce energy expenditure in the city by IDR5.14 trillion (USD436.80 million) per year, which is equivalent to half the city's energy bill and 9.5% of city-scale GDP in 2014. These returns mean that this package of low-carbon measures could pay back the investment in less than one year, and would continue to generate annual savings for the lifetime of the measures.

If the returns from these investments could be recovered and re-invested in low-carbon measures, we find that the city of Palembang could reduce its emissions by a further 1.7% (i.e. reductions of 25.8% against a BAU scenario). This would mobilise a total investment of IDR18.17 trillion (USD1.54 billion), which is equivalent to 33.6% of the city's annual GDP in 2014. This package of measures would generate annual cost savings of IDR5.50 trillion (USD467.4 million). With the deployment of this ‘cost-neutral’ package of measures, emissions from Palembang are forecast to rise by 96.4% between 2014 and 2025. Fig. 2 shows the carbon savings available to the city in this scenario according to sector.

The economic case for climate action is still compelling even at the much lower oil price of USD60 per barrel. On average, the payback period for low-carbon measures in the industry sector would triple, but collectively these investments still have an estimated payback period of less than one year. Similarly, the same package of low-carbon measures is cost-effective in the transport sector, although the economic case for implementing Euro IV standards is weakened.

In addition to a sectoral analysis, the potential emission reductions can also be apportioned according to the different strategies involved (see Fig. 3). This illustrates how the various sectors within a city offer different ways to reduce carbon emissions. It is quickly apparent that energy efficiency in the industrial sector and renewable energy from the waste sector offer the most carbon saving potential.

Energy efficiency measures provide 44.0% of the identified carbon saving potential, or 19.3MtCO_2-e relative to BAU levels. These savings are distributed across forty-eight different measures in the commercial, domestic and industrial sectors, as well as from the adoption of Euro IV standards for cars and motorbikes in the transport sector.

38.4% of the carbon saving potential comes from an expansion of renewable energy, which would reduce emissions by 16.8MtCO2-e relative to BAU levels. A significant proportion of

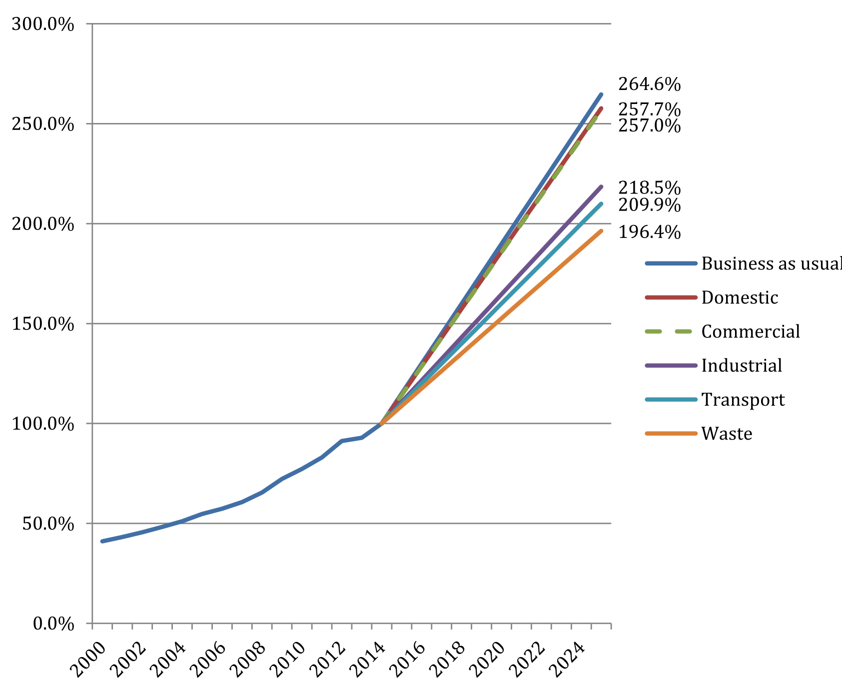

Fig. 2. Potential carbon savings available at no net cost to the city of Palembang, according to sector.

Fig. 3. Carbon saving potential available at no net cost to the city in 2025 by sector (left) and by strategy (right).

these savings would come from replacing diesel with biodiesel in the industry and transport sectors. As with large-scale electricity generation from biomass, such ambitious biofuel policies would demand a comprehensive review of the supply chains to ensure that the biofuels are broadly sustainable and less carbon-intensive than fossil fuel alternatives (i.e. do not involve land use change). The waste industry also offers significant potential to reduce emissions in the form of energy-from-waste infrastructure. This measure avoids methane emissions from the decomposition of municipal solid waste and offers additional carbon savings by displacing grid electricity generated from coal.

The largest opportunity for fuel switching in Palembang comes from replacing diesel generators with dual fuel systems, which would primarily affect the industrial sector. The carbon savings from changing urban form and function would involve establishing green building standards on 50% of new buildings in the domestic and commercial sectors, through the construction of bicycle lanes and through expanding the Bus Rapid Transport (BRT) system fourfold. These measures would all continue to yield substantial savings over their lifetimes. The remaining low-carbon measures are predominately in the waste sector, and include composting, waste prevention and recycling initiatives.

The economic and carbon savings from each of the low-carbon measures included in this analysis are detailed in Appendix B.

4. Discussion

4.1. The economic case for climate action

On purely economic terms, there is a compelling case for climate action in Palembang. With investments in energy efficiency, small-scale renewable energy and other low-carbon measures that would pay for themselves within a year, the city could reduce its energy bills by IDR5.14 trillion (USD436.80 million), the equivalent of 4.2% of annual GDP. These low-carbon options remain economically attractive even when oil prices fall as low as USD60 a barrel. There is therefore a strong economic incentive for local policymakers to integrate emission reduction targets into development planning, contradicting the prevailing belief that climate action is undertaken at the expense of economic growth.

From the perspective of national government, our work is a very conservative estimate of the economic case for climate mitigation for two reasons.

Firstly, energy efficiency measures reduce electricity consumption while renewable technologies (including energy-from-waste infrastructure) generate additional electricity. These policies would therefore reduce the total investment in energy infrastructure required to meet growing demand. For example, we find that that total electricity consumption in Palembang is expected to increase by 238.9% between 2014 and 2025 in a BAU scenario, but only by 184.8% with the implementation of cost-effective low-carbon measures. In other words, climate mitigation measures reduced projected growth in energy demand by almost 20%. The International Energy Agency forecasts that Southeast Asia will need to spend almost USD1.7 trillion on energy supply infrastructure in the period between 2014 and 2035 (IEA, 2013b, p. 12). If energy savings equivalent to those identified in this study could be delivered across Southeast Asia, that investment could be reduced by approximately USD20 billion per year. These savings would be additional to the energy savings outlined in Section 3.3.

Secondly, our estimates of energy expenditure are based on consumer prices and exclude the cost of subsidies. Kerosene, gasoline, diesel and electricity were all heavily subsidised until 2015; at one point, fuel subsidies in Indonesia reached 27.9% of the government's total budget (Dartanto, 2013, p. 119). We find that reducing subsidies (or taxing fuel) by IDR300 or IDR600 per litre is a very cost-effective way to reduce energy consumption and carbon emissions. While such subsidy reform has historically proven politically difficult in Indonesia (Granado et al., 2012), President Joko Widodo took advantage of low oil prices to remove gasoline subsidies in 2015 (Sambijantoro, 2015). This move increases fiscal space for more socially equitable investment in infrastructure and services (in 2008, the wealthiest 30% in Indonesia enjoyed almost 72% of gasoline subsidies (Dartanto, 2013)), but also exposes Indonesians to the volatile international oil market. There are therefore political and social reasons to invest in energy efficiency to ameliorate the impact of a rise in fuel prices on the cost of living or industrial competitiveness. Ambitious low-carbon policies could therefore complement subsidy reform. If the energy efficiency gains identified in this study could be delivered across Indonesia, consumption of electricity could be reduced by 20% and consumption of oil products by over 25%. Such an initiative would not only lessen the impact of an increase in energy prices on the public, but would also save government expenditure on electricity subsidies alone by approximately USD2 billion per year, based on the 2013 budget (GSI, 2014). This is a very compelling incentive for governments to integrate low-carbon measures into energy policy.

Our analysis is based on the current costs and benefits of different low-carbon options, and demonstrates that a wide range of measures is already economically feasible. For many of these, the investor will also be the beneficiary, for example, buyers of more energy efficient vehicles or appliances will recover the additional upfront costs from energy savings over the lifetime of the items. However, some of the low-carbon measures, particularly those in the cost-neutral package of investments, could require other cost-recovery mechanisms. Strategies to ensure that investors at least cover the full operating costs could include tiered pricing to minimise equity impacts (for example, see Ward and Pulido-Velazquez, 2009), complementary payments equal to the unit's cost plus the uplift margin minus the market revenues (for example, see Baslis et al., 2011) or the creation of energy efficiency revolving funds such as the one in Thailand (Grüning et al., 2012). This last option would be facilitated by public ownership of Indonesia's main electricity provider, PLN, and also has the advantage of ensuring closed loops in the public investment cycle.

In the longer term, such financial tools may not be necessary. The cost of many technologies has fallen substantially over recent decades (for example, see Islam et al., 2013; Timilsina et al., 2012), and breakthroughs are anticipated in others (for example, see Pollet et al., 2012; Stauffer et al., 2011). Such improvements could enhance the economic case for low-carbon investment at scale, and could prevent or reverse ‘lock in’ to high-carbon paths. Policy frameworks and the allocation of public financial resources consequently have a critical role to play to encourage technological substitution as these options become more economic (Kalkuhl et al., 2012; van der Vooren et al., 2012).

4.2. Governance of climate action

Indonesia was the first developing country to commit to ambitious emission reductions (Turner, 2011). This early leadership was largely a response to the high level of land-based emissions. Reducing deforestation and forest degradation in Indonesia remains the priority for climate policymakers, although energy-related emissions are growing as both a total and a proportion of Indonesia's carbon footprint (Resosudarmo et al., 2013).

A transition from a high- to low-carbon economy will demand effective energy governance in order to exploit the full range of climate mitigation options. Most low-carbon measures relating to energy currently face an exceedingly challenging domestic policy landscape (Gunningham, 2013). This is evident when we consider the case for switching the Palembang BRT network from diesel to compressed natural gas (CNG). This measure would avoid over 2.5MtCO_2-e by 2025 as well as substantially reducing air pollutants such as PM_{10} and SO_2. This measure would, firstly, require an upfront investment of IDR7.77 trillion (USD644 million) to upgrade the bus fleet, which is a major disincentive for the operators. Secondly, while CNG buses do have higher running costs than diesel buses, the diesel fleet additionally benefits from substantial fuel subsidies. This example illustrates how large-scale deployment of low-carbon measures is confounded by the higher upfront capital costs and greater policy risks compared to carbon-intensive options (Jacobs, 2012). Moreover, enabling policies are typically absent (for example, for green building standards or minimum energy performance standards) and energy incentives overwhelmingly take the form of subsidies for fossil fuels. In other cases, regulatory frameworks actively deter investment in low-carbon options, notably with respect to the unfavourable tender processes for geothermal energy compared with coal (Smith, 2012).

These factors help to explain why cost-effective opportunities have not been exploited in the city of Palembang. They also – problematically – suggest a lack of political will, institutional capacity or awareness of these opportunities. This is illustrated by considering the political economy of upgrading from Euro II to Euro IV standards for private vehicles. This reform could generate economic savings of approximately USD280,000 and avoid 2.4MtCO_2-e over the next decade, as well as generating substantial improvements to urban air quality and consequently respiratory health. The costs of compliance would not be borne by vehicle buyers, as most cars available on the market are already compatible with Euro IV standards. Rather, the constraint is the high sulphur and benzene content in diesel from domestic refineries; upgrading the refineries would cost an estimated USD800 million (Palguna and Safrudin, 2010).

These examples demonstrate that national governments and municipal authorities have a critical role to play in mobilising private capital (Schmidt, 2014). Public policies and resources are necessary to increase returns, reduce costs, de-risk low-carbon options and close knowledge or capacity gaps to unlock investment in climate mitigation (Buchner et al., 2013). This investment can come from a range of sources, illustrated in Fig. 4.

Much of the low-carbon investment could reasonably be expected to come from private actors. Some options may attract commercial investment without government support, while others may require awareness programmes, incentive schemes or regulation to ensure widespread uptake. For example, 13.1% of the identified carbon saving potential could be induced through the adoption of minimum energy performance standards for electronic appliances, lighting, new buildings and vehicles. With these policies in place, households and firms would provide the additional capital but could expect to quickly recover their investment through lower running costs (even with Indonesia's artificially low energy prices).

For other measures, there is evidence that some public finances would need to be allocated to new low-carbon technologies even when they are economically attractive. Subsidies, feed-in tariffs, renewable energy quotas and investment in technology-specific infrastructure are all considered effective policy tools for avoiding or overcoming technological ‘lock in’ (Kalkuhl et al., 2012; van der Vooren et al., 2012). In all cases, significant institutional capacity is needed to design locally appropriate standards or targets, collect locally specific energy data, enforce regulation and build consensus with both policymakers and consumers on the economic case for low-carbon investment (Sarkar and Singh, 2010). If national governments were reluctant to act, cities could possibly mobilise some behavioural change and investment through informational tools, though a voluntary approach is likely to capture only a fraction of the potential economic and carbon savings.

City authorities also have substantial capacity to reduce energy use and carbon emissions through urban planning. In this study, we find that green building standards and expanding the BRT system would yield carbon savings of nearly 3.0MtCO_2-e by 2025 (7.7% of the identified potential). However, this is a very conservative assessment of the impacts of these measures since more efficient infrastructure continues to yield savings over its lifetime. The benefits are not currently being realise because of a lack of local capacity to design or enforce housing standards: Indonesia currently has stringent urban land use regulation that gives

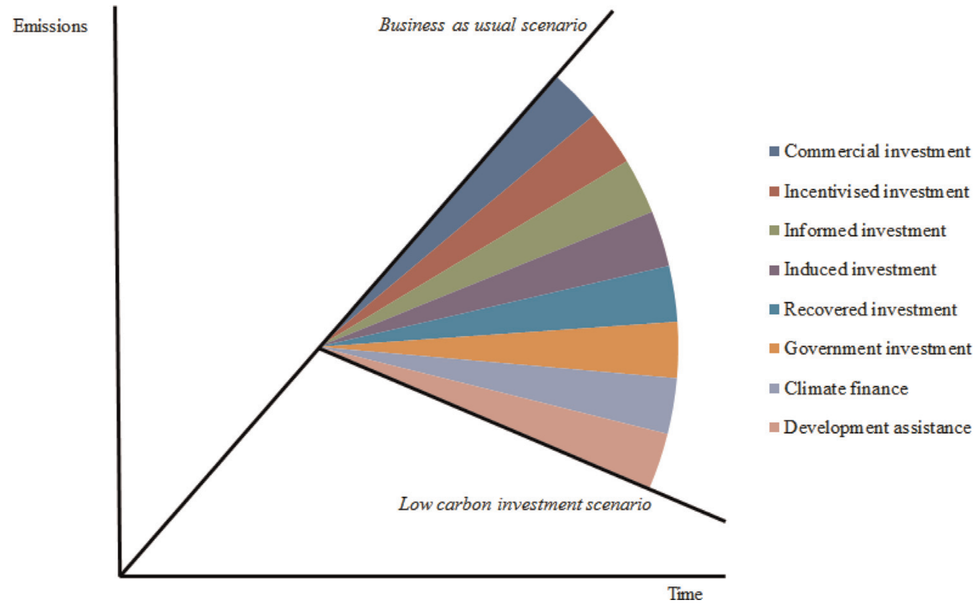

Fig. 4. Potential sources of investment in cost-effective and cost-neutral low carbon options in developing country cities.

municipal authorities extensive authority over urban development, but the majority of new housing in Indonesia is informal and self-built (Monkkonen, 2013). City councils could further improve the energy efficiency of the city by promoting compact urban development, specifically high-density living, transport-oriented development and mixed land use planning. Such measures were beyond the scope of this study.

The electricity, transport and waste sectors are all worth particularly close consideration with respect to climate mitigation. Low-carbon measures in these sectors include large-scale infrastructure options such as geothermal power, expanding the BRT system in Palembang and LFG utilisation. These measures may require significant technical capacity and larger upfront investments than high-carbon alternatives. However, they could be less institutionally complex to deliver than the array of low-carbon options in the domestic, commercial and industrial sectors, which offer relatively small carbon savings and require participation or oversight from multiple actors. Large-scale infrastructure options may therefore be an attractive starting point for government agencies to build momentum and capacity – particularly if they can unlock commercial investment or attract international climate finance.

The economic case for geothermal power is particularly significant. Indonesia must expand its electricity supply dramatically in order to meet its development goals, but it needs to generate this electricity from low-carbon sources if it is to simultaneously reduce the carbon intensity of economic activity. We find that geothermal power is the most cost-effective option in the electricity sector and, on purely economic terms, should be preferentially developed to meet new demand for base load electricity. The regulatory barriers discussed in Section 3.2 suggest an urgent need for policy reform at a national scale, particularly in light of private and multilateral interest in geothermal investment. Specifically, indirect subsidies for coal would need to end and calculates that incentives for geothermal investments (in the form of feed-in tariffs) would need to be increased by nearly 20% to make new plants attractive to early adopters. This is perhaps the area where more effective energy governance is most urgently needed if Indonesia is to transition to a low-carbon economy.

4.3. The social case for climate action

It is clear that there is a strong economic case for low-carbon investment, and that both local and national governments can mobilise this investment through a range of policy tools. However, it is also important to evaluate these measures to ensure that climate action contributes towards broader development goals such as reducing energy poverty.

With careful design and implementation, many of the individual low-carbon measures identified in this study could support development goals. Public transport systems including BRTs and bicycle lanes disproportionately benefit the urban poor by improving mobility and decreasing transport times and air pollution (Vasconcellos, 2001). Waste management systems also particularly benefit the poor, who cannot insulate themselves from environmental degradation and public health risks. There is also scope for job creation in waste collection, recycling and compost schemes (Chin, 2011).

However, some of the low-carbon measures that we identify as cost-effective may have negative social impacts. Many of the opportunities identified in the domestic and transport sector are primarily available to higher-income households who are more likely to purchase electronic appliances, vehicles or solar PV panels. While improving energy efficiency might make more resources available for consumption in the long-term, poorer households would struggle in the short-term to cover the higher upfront costs of low-carbon options such as compact fluorescent light bulbs or more efficient appliances. Populations experiencing energy poverty would save little from energy efficiency measures, apart perhaps from green building standards (Ürge-Vorsatz and Herrero, 2012). In the domestic and transport sectors, therefore, climate action will require a complementary suite of policies to address energy access and energy poverty. This underscores the fact that the economic case for low-carbon investment is not sufficient for action: issues of equity need to be mainstreamed into development planning (Casillas and Kammen, 2012).

Similarly, there is a risk that some of these energy efficiency measures would have 'rebound effects', whereby energy efficiency measures actually drive greater energy use. This can happen at an individual scale, for example because the economic savings are used to purchase new energy-intensive goods, at an economy-wide scale, by stimulating growth and therefore further energy demand (Madlener and Alcott, 2009). Some empirical studies suggest that rebound effects in developing countries may exceed 100% (van den Bergh, 2011), but estimates from meta-reviews in OECD countries suggest that the long-run feedback effects for consumer energy services are unlikely to exceed 30% (Sorrell, 2007). Cost-recovery mechanisms such as a revolving fund could reduce these direct rebound effects. However, there is also a need to minimise indirect rebound effects, ideally through energy price regulation or tradable permits (van den Bergh, 2011). This consideration underscores the limitations of technical efficiency gains relative to the rate of economic growth in a city like Palembang. Fuel subsidy reform, an expansion of clean electricity generation and public engagement with climate action will be necessary if Indonesia is to slow the increase of energy-related carbon emissions.

5. Conclusion and recommendations

We find a compelling economic case for climate change mitigation at the city scale. Investment in low-carbon measures would yield substantial financial savings – even when oil prices fall substantially from the high levels of early 2014 – by reducing expenditure on energy bills, energy subsidies and energy infrastructure. Despite the prevailing perception that ambitious climate action entails opportunity costs for development, the limitations on climate action seem to be political and institutional rather than economic. Rapidly growing cities are therefore being 'locked in' to high-carbon economic models as a consequence of capacity deficits, non-decisions and ad hoc development.

The presence of a strong economic case for low-carbon investment provides an attractive opportunity to engage new actors and unlock new streams of investment in climate mitigation. As policymakers grapple with the costs of energy subsidies and infrastructure, the economic returns from climate action should be increasingly compelling. Local and national authorities have a wide range of policy tools available to them to mobilise private investment in climate mitigation. Policymakers can cherry-pick low-carbon options that are both economically attractive and institutionally straightforward – for example, geothermal energy, landfill gas utilisation, green building standards for the commercial sector and energy efficient air conditioners – as a means to build local capacity and demonstrate economic or technical feasibility. Enforcing existing energy regulation and streamlining planning processes can also provide a platform for more ambitious initiatives, such as transport-oriented urban planning, large-scale deployment of decentralised renewable energy technologies or the creation of revolving funds to support industrial energy efficiency investments.

The rapid, unmanaged growth of developing country cities means that policymakers in these contexts will find it difficult to fully exploit the full potential of economically attractive low-carbon measures. Even if they could, these investments would not halt the growth in emissions: if the profits of all cost-effective options were re-invested in other low-carbon measures, emissions from Palembang would still rise by 96.4% between 2014 and 2025. There is also a need for complementary policies to ensure social inclusivity and minimise indirect rebound effects. However, reducing the carbon intensity of growth gains city councils and national authorities time to develop supporting institutions, reduce the costs and risks associated with low-carbon investment and build the evidence base for clean energy. With future growth in carbon emissions concentrated in developing world cities, it is imperative that policymakers begin to build the momentum and capacity to integrate climate mitigation objectives into urban planning. The presence of a compelling economic case for low-carbon development will hopefully help to overcome the current inertia and catalyse ambitious climate action in rapidly growing cities in the developing world.

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Appendix A. Supplementary material

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