The Economics of Low Carbon Cities

Kolkata, India

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Today

9.1% of city-scale GDP leaves the local economy every year through payment of the energy bill. In 2025, this is forecast to be 8.1% of GDP.

9.1% of GDP leaks out of the economy

Tomorrow

Investment 0.6% of GDP p.a.

Leads to...

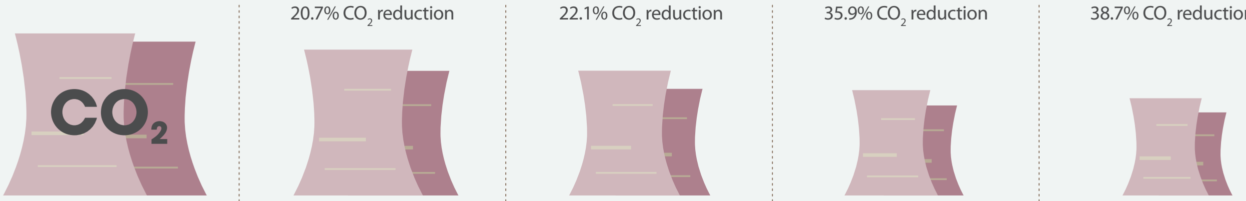
0.6% of GDP could be profitably invested, every year for ten years, to exploit commercially attractive energy efficiency and low carbon opportunities.

- **Energy**
  Reduction in the energy bill equalling 1.6% of GDP
- **Financial viability**
  3.9 years to pay for themselves
- **Employment**
  more jobs and skills in low carbon goods and services
- **Wider economic benefits**
  energy security, increased competitiveness, extra GDP
- **Wider social benefits**
  reductions in fuel poverty, improvements in health

Potential to reduce CO_2 emissions

2000 | 2025

20.7% CO_2 reduction	22.1% CO_2 reduction	35.9% CO_2 reduction	38.7% CO_2 reduction



Through cost effective investments that would more than pay for themselves on commercial terms over their lifetime.	If, as well as the above investments, cost effective investments in the electricity sector were made that could more than pay for themselves on commercial terms over their lifetime.	With cost neutral measures that could be paid for by re-investing the income generated from cost effective measures.	With cost neutral measures in the electricity sector that could be paid for by re-investing the income generated from cost-effective measures.

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The Economics of a Low Carbon Kolkata

Executive Summary

More than half of the world's population lives in cities, and up to 70% of production and consumption takes place in cities.[1] Currently, activities in cities consume up to 70% of all energy and are responsible for up to 70% of all carbon emissions.[2]

Energy is obviously central to the future development of cities – but is it possible that cities could shift to energy efficient, low carbon development paths? Focusing on the Kolkata Metropolitan Area, this report considers the ways in which the relationship between energy, carbon and development could be changed in a rapidly growing city with pressing development needs.

Although the report considers energy supply, the main aim is to review the cost and carbon effectiveness of a wide range of energy efficient and low carbon measures that could be applied in different sectors in Kolkata. It then considers whether there is an economic case for major investments in these measures across the city, and whether these investments have the potential to shift the city on to a more energy efficient, low carbon development path.

The Indian Context

India has the largest energy demand in the world after China and the United States, and its demand is rising rapidly – it has more than doubled since 1990, and is forecast to grow by a factor of 4.5 between 2012 and 2035. However, per capita energy demand in India remains low – per capita demand is 14% of the OECD average, 34% of the average Chinese level and 87% of the average African level.[3] Even though Indian energy is relatively carbon intensive, these levels of consumption mean per capita emissions in India are only one third of the world average.

India has stated that it must be able to increase energy use per capita – and correspondingly its absolute levels of carbon emissions – to allow it to achieve inclusive growth and eliminate poverty.[4] It has however committed to emission intensity reduction targets of 20-25% on 2005 levels by 2020 (excluding emissions from agriculture) and plans to meet these predominantly through support for energy efficient technologies and energy conservation measures.[5]

India has already made substantial progress towards this goal, having achieved economic growth rates of 9% per annum and constrained its energy growth rate to less than 4% per annum since 2004.[6]

The future development of India – and the role that energy plays in development – will depend to a significant extent on what happens in Indian cities. Currently, 32% (384m) of the 1.2 billion population of India lives in cities[7], and by 2030 it is predicted that up to 40% (600m) people of the forecast 1.5 billion population will live in cities.[8] Economically, 58% of Indian GDP comes from cities, and this is forecast to grow to 70% by 2030.[9] Socially, there are major inequalities in Indian cities, with a small but growing urban elite, a larger and more rapidly growing urban middle class, and a very substantial urban poor who frequently live in informal settlements with multiple development challenges including chronic overcrowding and limited access to modern energy.

Kolkata

Kolkata is the third largest city in India and the 19th largest urban area in the world.[10] Some forecasts suggest that Kolkata's population could reach 23m by 2030.[11] There are significant inequalities and pressing development needs in Kolkata, but institutional capacities to address these are over-stretched. Some estimates suggest that Kolkata will require US$109bn in capital expenditure between 2010 and 2030 to meet its human development goals.[12]

While imposing substantial challenges, the high growth rates that the city is encountering and the need for new infrastructure to support this growth create opportunities for interventions that could influence the city's development trajectory. If Kolkata achieves its target growth rates of 6-7% a year, more than half of the urban economy that will exist in 2025 has yet to be developed or built. Integrating energy efficiency and low carbon goals into the city's development therefore offers the chance to shift the city on to a more efficient and sustainable energy trajectory. Initial investment requirements might be higher, but ongoing costs will be lower and the city economy will be more efficient and resilient. If done well, this could also improve the quality of life for all residents in the city.

Our Aims

What is the best way to shift Kolkata to a more energy efficient, low carbon development path? Even where there is broad interest in such a transition, there are some major obstacles that often prevent action on such a broad agenda. The absence of a credible and locally appropriate evidence base makes it particularly difficult for decision makers to act.

This study aims to provide such an evidence base for Kolkata, and to use this to examine whether there is an economic case that can be used to secure large-scale investments in energy efficiency and low carbon development in the city. The more specific aim is to provide prioritized lists of the most cost and carbon effective measures that could realistically be adopted across the energy, housing, commercial buildings, transport, industry and waste sectors within the city.

Our Approach

We start the analysis by collecting data on levels and composition of energy use in Kolkata. We do this for a range of different sectors including the electricity sector on the supply side and the housing, commercial buildings, transport and industry sectors on the demand side. We also evaluate the waste sector as it both generates greenhouse gas emissions and has the potential to generate energy.

For each of these sectors, and for the city as a whole, we examine the influence of recent trends, for example in economic growth, population growth, consumer behavior and energy efficiency, and develop 'business as usual' baselines that continue these trends through to 2025. These baselines allow us to predict future levels and forms of energy supply and demand, as well as future energy bills and carbon emissions.

We then compile lists of many of the energy efficiency, small-scale renewables and low carbon measures that could potentially be applied in each of the different sectors in the city. We assess the performance of each measure by conducting a realistic assessment of its costs and likely lifetime savings, and consider the scope for deploying each one in Kolkata in the period to 2025. These appraisals are subjected to a participatory review in expert workshops to ensure that they are as realistic as possible. We then compare the impact of all future activities against the business as usual baselines.

We draw together the results from our assessment to determine the potential impact of the combined measures across the different sectors of the city as a whole. This allows us to understand the scale of the development opportunity, the associated investment needs and paybacks, as well as impacts on energy supply and demand, bills and carbon emissions in the different sectors in the city. These aggregations also allow us to generate league tables of the most cost and carbon effective measures that could be adopted both in each sector and across the city as a whole.

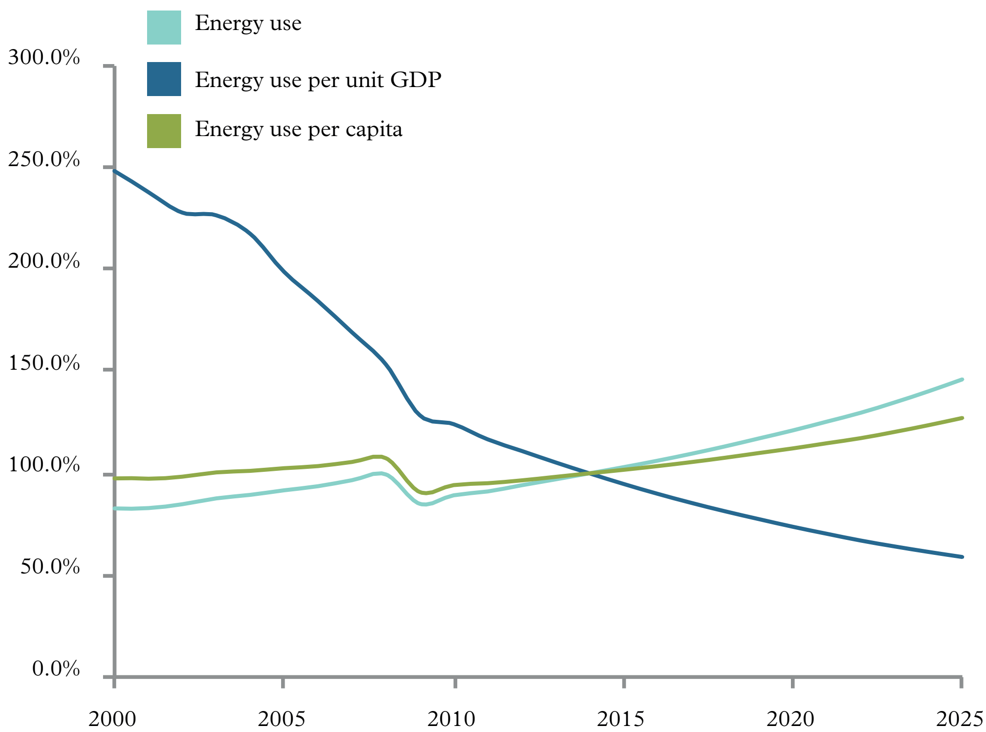
The Changing Context and the Impacts of Business as Usual Trends

We find that Kolkata's GDP in 2014 was INR 1.84 trillion (US$31.5 billion), and if recent trends continue we forecast that GDP will grow to INR 4.4 trillion (US$75.2 billion) by 2025. This means that the average per capita income in Kolkata was INR 125,109 (US$2,139) in 2014 and that with projected rates of economic and population growth we predict that this will grow to INR 278,710 (US$4,766) by 2025. We also find that the total energy bill for Kolkata in 2014 was INR 169.2 billion (US$2.9 billion), which equates to 9.1% of GDP. In other words, we find that 9.1% of all income earned in Kolkata is currently spent on energy.

Business as usual trends in Kolkata show a rapid decoupling of economic output and energy use between 2000 and 2025 (see Fig. 1). However, GDP and energy demand per capita are both rising steadily, while the population of Kolkata is also growing. These effects are offsetting the improvements in energy intensity and leading to a net increase in energy use.

Real energy prices are projected to increase steadily, with the exception of coal. The rising real energy prices combined with increasing energy consumption means that the total energy bill for Kolkata will more than double its 2012 level by 2025 in a business as usual scenario.

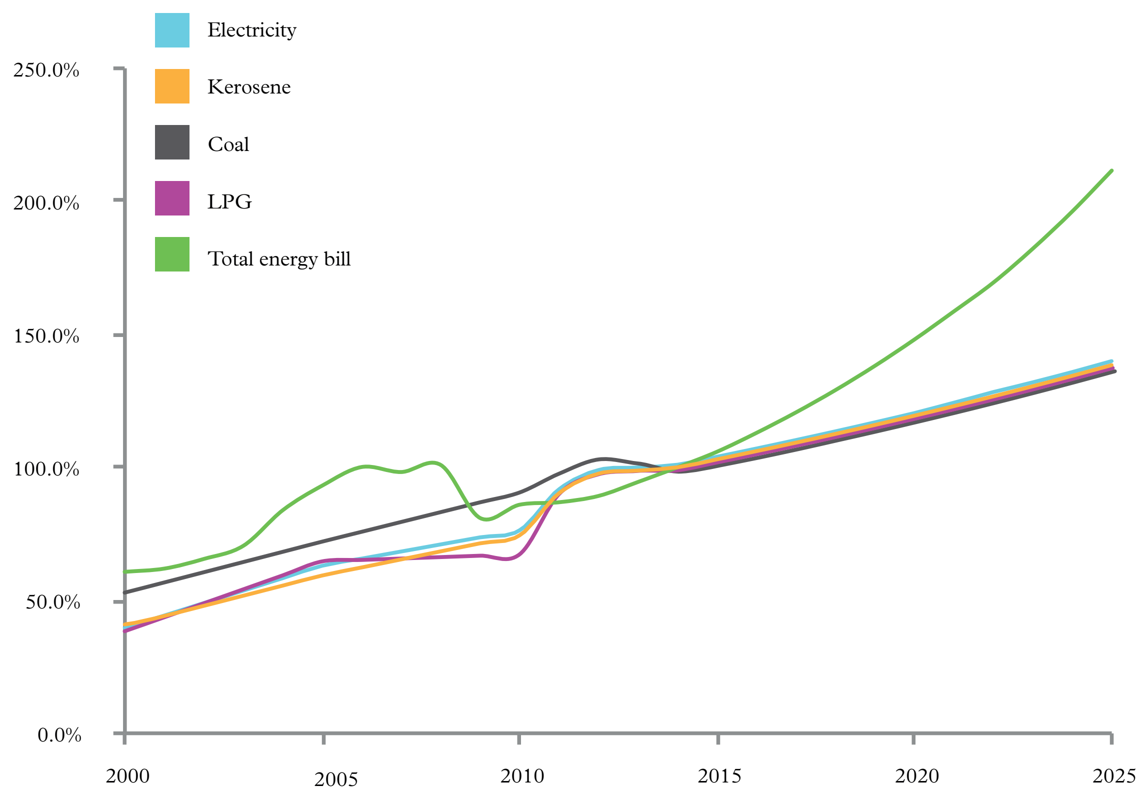
Figure 1: Indexed energy use – total, per unit of GDP and per capita.



Our analysis finds that the emissions intensity of energy production is projected to remain largely constant until 2025, but increasing energy efficiency in the wider economy means that the emissions produced per unit of GDP will fall dramatically between 2000 and 2025. This is significant because this is the index that India is using in their national carbon targets in international negotiations. It is important to note that, despite declining emission intensity per unit of GDP, rapid economic growth still means that emissions per capita and total emissions are continuing to rise. In a business as usual scenario, total emissions from Kolkata are therefore forecast to increase by 54.0% on 2014 levels by 2025.

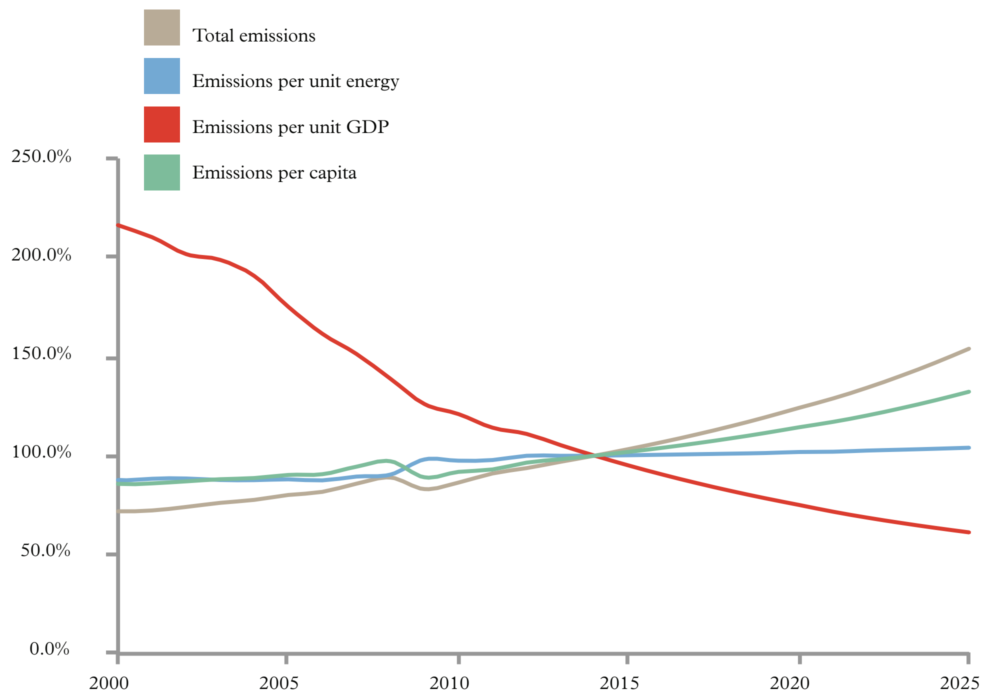
The total energy bill for Kolkata in 2014 was INR 169.2 billion (US$2.89 billion). 9.1% of all income earned in Kolkata is spent on energy.

Figure 2: Indexed energy prices and total energy bill.



A continuation of business as usual trends in Kolkata will see energy use rise by 44.1%, total energy bills by 111.6% and carbon emissions by 54.0% by 2025.

Figure 3: Indexed carbon emissions – total, per unit of energy, per unit of GDP and per capita.



The Potential for Carbon Reduction

For Kolkata as a whole, we predict that – compared to 2014 – a continuation of recent business as usual trends in the period to 2025 would see total energy use rising by 44.1% from current levels, with energy bills rising by 111.6% and carbon footprints rising by 54.0%.

Kolkata could reduce its energy bills by INR 30.4 billion (US$520.7 million) and its carbon emissions by 20.7% through investments that would pay for themselves in 3.9 years.

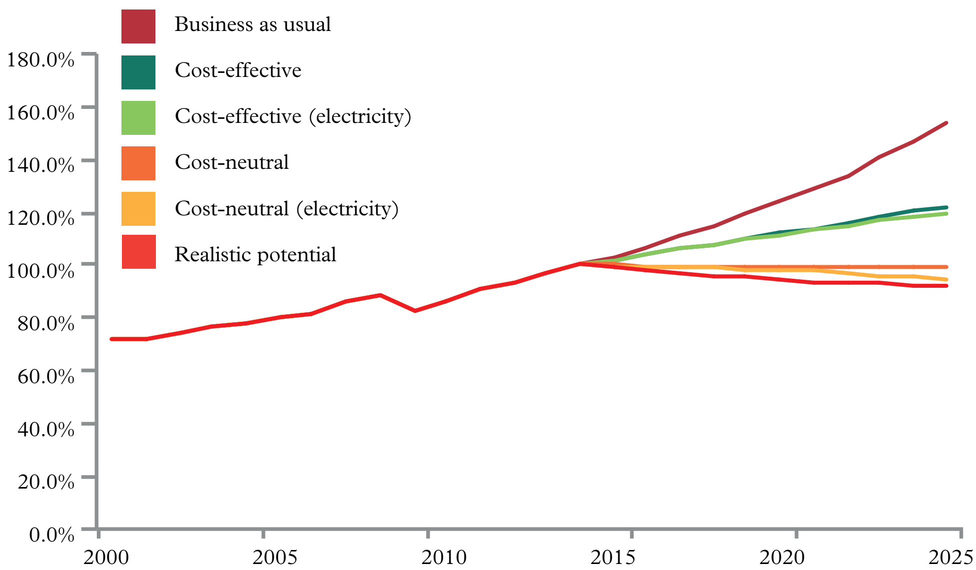
We find that – compared to business as usual trends – Kolkata could reduce its carbon emissions by 2025 by:

- 20.7% through cost effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require an investment of INR 119.3 billion (US$2.0 billion), generating annual savings of INR 30.4 billion (US$520.7 million), paying back the investment in 3.9 years and generating annual savings for the lifetime of the measures.
- 22.1% if, as well as the above investments, cost effective investments in the electricity sector were made that could more than pay for themselves on commercial terms over their lifetime. This would require an investment of INR 39.7 billion (US$ 679 million), generating annual savings of INR 18.2 billion (US$ 311.8 million), paying back the investment in 2.2 years and generating annual savings across West Bengal for the lifetime of the measures.
- 35.9% with cost neutral measures that could be paid for by re-investing the income generated from cost-effective measures. This would require an investment of INR 205.6 billion (US$ 3.6 billion), generating annual cost savings of INR 33.5 billion (US$ 573.6 million), paying back the investment in 6.2 years and generating annual savings for the lifetime of the measures.
- 38.7% with cost neutral measures in the electricity sector that could be paid for by re-investing the income generated from cost-effective measures. This would require an investment of INR 210.4 billion (US$ 3.6 billion), generating annual cost savings of INR 27.0 billion (US$ 462.0 million), paying back the investment in 7.9 years and generating annual savings across West Bengal for the lifetime of the measures.
- 43.5% with the exploitation of all of the realistic potential of all the different measures with carbon saving potential. This would require an investment of INR 473.8 billion (US$8.4 billion), generating annual savings of INR 24.5 billion (US$462 million), paying back the investment in 7.9 years and generating annual savings for the lifetime of the measures.

The impacts of all of these levels of change are shown in Figure 4 on the page opposite.

The study reveals a compelling economic case for large-scale investment in energy efficiency, renewable energy and low carbon development in Kolkata.

Figure 4: Emissions from Kolkata under six different scenarios between 2000 and 2025.



Discussion

Our analysis reveals that business as usual trends in Kolkata show a rapid decoupling of economic output, energy use and carbon emissions between 2000 and 2025. In other words, the carbon intensity of GDP is decreasing rapidly and – in relative terms – the city is already transitioning to a more energy efficient and low carbon development model. The rates of reduction in the carbon intensity of GDP are substantially higher than those targeted by the Indian government in the National Climate Action Plan.

However, population and economic growth in Kolkata is so rapid that it offsets the improvements in energy and carbon intensity. Absolute levels of energy use are projected to rise at a rate of 3.31% per annum between 2014 and 2025. This will lead to an increase in annual energy bills of 111.6% to INR 357.9 billion ($US 6.1 billion) per year and of net emissions of 54.0% to 37.8MtCO_2-e over the same period.

This study reveals a compelling economic case for large-scale investment in energy efficiency, renewable energy and low carbon development in Kolkata above and beyond these background trends. By 2025, the city can cut its emissions by 20.7% when compared to the business as usual scenario through cost-effective investments that, by reducing energy bills, would pay for themselves on commercial terms in 3.9 years. If the profits from these investments are re-invested in low carbon measures, Kolkata can slash its emissions to 35.9% relative to business as usual trends and recover its investment in 6.2 years. These low carbon measures would continue to generate savings on energy bills throughout their lifetime.

The massive expansion of infrastructure projected for Kolkata – like most cities in fast-growing emerging economies – provides an opportunity to integrate climate considerations into urban planning at a relatively early stage. Such an approach improves both the cost and carbon effectiveness of most low carbon options and would significantly enhance Kolkata’s efforts to transition to a more energy efficient and low carbon economy/society.

Conclusions and Recommendations

This research reveals that there are many economically attractive opportunities to increase energy efficiency and stimulate renewable energy, which would in turn improve the economic competitiveness, energy security and carbon intensity of Kolkata.

Clearly, however, the presence of such opportunities does not mean that they will actually be exploited. By providing evidence on the scale and the composition of these opportunities, we hope that this report will help to build political commitment and institutional capacities for change. We also hope this report will help Kolkata to secure the investments and to develop the delivery models needed to implement change. Some of the energy efficiency and low carbon opportunities could be commercially attractive whilst others may only be accessible with development assistance. Many of the opportunities would benefit from the support of enabling policies from government.

But fundamentally, we should recognise that economics is not the only discipline that has something useful to say on the transition to a low carbon economy/society. A wider analysis should also consider the social desirability of the different options, as well as issues relating to the equity, inclusivity and broader sustainability of the different pathways towards a low carbon economy and society in Kolkata.

Chapter 1.
Introduction, Context, Aims and Objectives

Cities, Energy, Carbon and Climate

The influence and impact of cities cannot be overstated. More than half of the world's population lives in cities, and up to 70% of production and consumption takes place in cities.[13] Cities are the places where many of the world's institutions and much of its infrastructure are located, and where many of the world's major social, economic and environmental challenges are created, experienced and sometimes tackled. Cities are also the places where many international and national policies and plans must ultimately take effect. Global action frequently relies on urban action – our common future depends to a large degree on the way that we develop, organise, live and work in cities.

One of the key issues in the future of cities is energy. Currently, activities in cities consume up to 70% of all energy and are responsible for up to 70% of all carbon emissions.[14] Some estimates suggest that around 10% of all income that is earned in cities is spent on energy.[3] Despite its costs and impacts, modern energy is critical to human wellbeing. It enhances quality of life and enables economic activity. Increasing energy supplies and improving energy access enables development. The challenge is achieving sustainable and affordable energy provision – how can cities shift to energy efficient, low carbon development paths?

Cities' share of global emissions is high and rising fast, but their institutional capacity and socio-economic dynamism also means that cities are uniquely positioned to tackle climate change. This is particularly true in fast-growing emerging economies where massive investment in infrastructure provides an opportunity to slash the energy and carbon intensity of social and economic activity. It is often suggested that preparing for climate change at an early stage of development is more effective and economically attractive than replacing or upgrading established infrastructure. Mainstreaming energy efficiency and low carbon objectives into planning processes has the potential to reduce energy bills, increase energy access, improve air quality, ease congestion, create jobs and mitigate the impacts of climate change.

Focusing on greater Kolkata, this report considers the ways in which the relationship between energy and development in a rapidly growing city with pressing development needs could be changed. Although the report considers energy supply, the main aim is to review the cost and carbon effectiveness of a wide range of energy efficient, renewable energy and low carbon options that could be applied in different sectors in Kolkata. It then considers whether there is an economic case for major investments in these options across the city, and whether these investments have the potential to shift the city on to a more energy efficient, low carbon development path.

The Indian Context

India's energy demand more than doubled between 1990 and 2009, from 319 million tonnes of oil equivalent (Mtoe) to 669 Mtoe.[15] Today, it has the third largest energy demand in the world after China and the United States. Recent increases in energy consumption have predominately come from the power sector as it meets growing demand for electricity in the industrial, residential and commercial sectors. The power sector's share of total primary energy demand increased from 23% to 38% between 1990 and 2009. Transport has also contributed significantly, with an increase from 8% to 14% of energy demand in the same period.[16] For the future, India's total primary energy demand is forecast to more than double to 1,464Mtoe by 2035.[17] If realised, this would mean that demand for energy in India has risen by 450% in 45 years. In 2009 India's fuel mix comprised 42% coal, 25% biomass, 24% oil and 7% natural gas.[18] However, the share of biomass is predicted to fall to 15% of the fuel mix by 2035, with energy generated from coal in particular more than doubling in this period.[19]

Individual energy consumption remains low in India at 0.58toe per capita, compared to the OECD average of 4.28, China of 1.7 or Africa at 0.67.[20] Even though energy is relatively carbon intensive, these levels of consumption mean per capita emissions in India are only one third of the world average and 14% of the OECD average. As a result, India has explicitly rejected absolute carbon reduction targets[21] and stated that it must be able to increase carbon emissions to allow it to achieve inclusive growth and eliminate poverty.[22]

Nonetheless, in its National Action Plan on Climate Change, the national government has committed to emission intensity reduction targets of 20-25% on 2005 levels by 2020 (excluding emissions from agriculture), predominately through support for energy efficient technologies and energy conservation measures.[23] India has already made substantial progress towards this goal, having achieved economic growth rates of 9% per annum and constrained energy growth rate to less than 4% per annum since 2004.[24] India is also seeking to expand the contribution of clean energy technologies through imposing a carbon levy on coal to fund clean energy programmes and by accessing financial and technical assistance from developed countries.

This broader context on energy and climate in India is directly relevant to cities. Currently, 32% (384m) of the 1.2 billion population of India lives in cities, and by 2030 it is predicted that up to 40% (600m) people of the forecast 1.5 billion population will live in cities.[25] Economically, 58% of Indian GDP comes from cities, and this is forecast to grow to 70% by 2030.[26] Socially, there are major inequalities in Indian cities, with a small but growing urban elite, a larger and more rapidly growing urban middle class, and a very substantial urban poor who frequently live in informal settlements with multiple development challenges including chronic overcrowding and limited access to modern energy as well as a range of other critically important services. The inter-relationships between energy and cities are therefore pronounced.

The West Bengal Context

Industry consumes the largest share of energy in West Bengal (47%), followed by domestic (25%) and commercial (11%) energy use, predominately in the form of electricity.[27] The state also directly consumes5.5Mt of petroleum products, predominately for transport (42%) and cooking/lighting in the domestic and commercial sectors (26%).[28]

The installed electricity capacity of the West Bengal Power Utility was 9892MW in 2011, with 96% of electricity generated from coal-based power stations.[29] These are primarily supplied with low-grade, non-coking domestic coal. This type of coal dominates Indian reserves and is regarded as suitable mostly for use in the power sector rather than industry. Its poor quality and high ash content contribute significantly to the carbon-intensive and polluting nature of the electricity sector in India. Moreover, the grid serving West Bengal is particularly carbon inefficient. Global best practice from this grade of coal generates less than 0.75tCO_2-e/MWh[30] and most electricity in India has a carbon intensity of 0.8tCO_2-e/MWh.[31] We calculate that the electricity consumed in Kolkata has a carbon intensity of 1.52tCO_2-e/MWh.

This dependence on hydrocarbons looks likely to continue as the state invests in increasing electricity capacity to help meet growing energy needs, with additional coal-fired and gas-based power stations recently completed and currently under construction. The state utility is also adopting efficiency measures to improve the energy intensity of economic activity: notably, distribution losses were reduced from 34.4% to 22.8% between 2004 and 2009. Substantial investment in new capacity and energy efficiency will still be required to meet growing electricity demand, which is projected to increase by a factor of 3.5 by 2031.[32]

There is a marked divide between the urban and rural energy mix in West Bengal. Rural households use kerosene for 65% of lighting needs while urban households overwhelmingly use electricity (87%); biomass provides 74% of energy for cooking in rural households, but LPG (46%) and coal (19%) are the main cooking fuels in urban areas. [24] The state is seeking to redress this inequality in clean energy access through ambitious rural electrification and kerosene-to-LPG programmes, though this will also likely increase the carbon intensity of rural energy consumption.

There is a preliminary West Bengal State Climate Change Action Plan. The state's climate change mitigation strategy entails increasing the share of renewable energy, particularly large-scale solar photovoltaic power, increasing supply-side energy efficiency in the grid and supporting the adoption of demand-side energy efficiency measures. These currently include mandatory energy rating programmes for domestic appliances, waste heat recovery policies in industry, an LED street lighting campaign and public awareness programmes. The State Climate Change Action Plan however, does not specify carbon intensity or renewable energy targets.

Kolkata

Kolkata is the third largest and the most densely populated city in India and the 19th largest urban area in the world.[33] Officially, its population is 14.1m and it is currently growing at a rate of 6.9% per year.[34] Some forecasts suggest that Kolkata's population could grow to 23m by 2030.[35] There are stark inequalities within Kolkata. More than a third of Kolkata's population live in slums, where a third of the population are unemployed.[36] 40% of the city's population and a majority of the slum population work in the informal sector.[37] Kolkata's residents often face insufficient water supplies, inadequate sanitation systems, poor air quality, limited housing stock and scarce green space.[38]

Institutionally, public budgets in Kolkata are overstretched, but massive additional investment in Kolkata's urban infrastructure is necessary to fulfil India's human development goals. Recent assessments have predicted that Kolkata will require $109bn in capital expenditure between 2010 and 2030 to meet its human development goals.[39] Even if it is accurate, of course this figure need not be fixed: clearly there are better and worse ways of investing in development, and different development pathways are available. But it is equally clear that new forms of investment will be needed – not least in energy supply and demand – to enable development to take place.

The proposed spatial distribution and type of infrastructure outlined in the Kolkata Metropolitan Development Authority (KMDA)'s Vision 2025 is key to predicting energy and carbon trends in the city. KMDA has planned massive infrastructure expansion programmes in industry, housing and transport.[40] This is intended to redress historical deficits in infrastructure investment and maintain current economic growth rates. While imposing substantial challenges, the inadequacy of established infrastructure and the high growth rates also offer opportunities to influence the city's development trajectory to ensure that environmental limitations do not curtail human development or economic growth. If Kolkata achieves its target growth rates of 6-7% a year, more than half of the urban economy that will exist in 2025 has not been built yet. Integrating energy efficiency and low carbon goals into the city's development therefore offers the chance to shift the city on to a more cost-efficient and sustainable energy trajectory. Initial investment requirements might be higher, but ongoing costs will be lower and the city economy will be more resilient to volatile fuel prices and climate change impacts.

Aims and Objectives

What is the best way to shift a city to a more energy efficient, low carbon development path? Even where there is broad interest in such a transition, there are some major obstacles that often prevent cities from acting on such a broad agenda. The absence of a credible and locally appropriate evidence base makes it particularly difficult for decision makers to act.

This study aims to provide such an evidence base for Kolkata, and to use this to examine whether there is an economic case that can be used to secure large-scale investments in energy efficiency and low carbon development in the city. The more specific aim is to provide prioritised lists of the most cost and carbon effective measures that could realistically be promoted across the energy, housing, commercial buildings, transport, industry and waste within the city.

We seek to map broad trends in energy use, energy expenditure and carbon emissions in Kolkata, and examine the implications of 'business as usual' development in the city. This macro-level context aims to demonstrate the importance of energy efficiency and energy security at the city scale with the goal of mobilising high-level action around these issues.

The evidence base is intended to inform policymaking and programme design both within individual sectors and at the city scale. By identifying the most cost- and carbon-effective measures, we aim to help development agencies, government, industry and civil society organisations to design low carbon strategies that exploit the most attractive opportunities. Notably, the evidence base has the potential to underpin national applications to international climate funds, development banks and other financial organisations, thereby helping to unlock and direct large-scale investment into energy efficient, low carbon development.

The study also aims to evaluate the scope for green growth in urban India. It is intended to identify all significant 'win-win' low carbon opportunities, and to inform the extent to which economic development and energy use can be decoupled in an economically feasible way. This in turn is intended to inform broad discussions about the costs, benefits and realities of climate change mitigation in a developing country context.

Chapter 2.
Approach to the Analysis

Our analysis has a number of key stages.

Baseline analysis.
We start by collecting data that enables us to understand the levels and composition of energy supply to, and demand in Kolkata. We do this for a range of different sectors including the energy sector on the supply side and the housing, commercial buildings, transport and industry sectors on the demand side. We also evaluate the waste sector as it both generates greenhouse gas emissions, and has the potential to generate energy.

For each of these sectors, and for the city as a whole, we examine the influence of recent trends, for example in economic growth, population growth, consumer behaviour and energy efficiency, and we develop business as usual baselines based on the continuation of these trends through to 2025. These baselines allow us to predict future levels and forms of energy supply and demand, as well as future energy bills and carbon footprints. We then compare all future activities against these baselines.

Identification and Assessment of Measures
We develop lists of all the energy efficiency, small scale renewables and low carbon measures that could potentially be applied in each of the different sectors in the city. We include both technological and behavioral measures. We first develop long lists of all potential measures, based on extensive literature reviews and stakeholder consultations, and we then review these to remove any options that are not applicable in the Kolkata context. The outputs then form our shortlist of measures for each sector. These shortlists are not necessarily exhaustive – some measures may have been overlooked, 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 assess the performance of each measure on the shortlist. We consider the capital, running and maintenance costs of each measure, focusing on the marginal or extra costs of adopting a more energy efficient or lower carbon alternative. We then conduct a realistic assessment of the likely savings of each option over its lifetime, taking into account installation and performance gaps. As each measure could be in place for many years, we take into account changing carbon intensities of energy use and assume an average annual rise of 3% in real prices (including energy).

Some of the measures interact with each other, so their performance depends on whether/to what extent another option is also adopted. For example, the carbon saving from most measures depends 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 adopting green building standards depend on whether there are also energy efficiency standards for air conditioners. To take these interactions into account, we calculate the impacts of each measure if adopted independently with business as usual conditions in energy supply.

These calculations underpin the figures in the league tables. When we are determining the potential savings across a sector or across the city economy, we calculate 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 reducing the carbon intensity of the grid.

In many cases, a single measure has been considered under varying policy conditions: for example, solar photovoltaic panels with and without feed-in tariffs. When compiling the sector or economy-wide summaries, the cost-effective options which require the least enabling policies have been included unless these are already established at scale. Therefore, the total investment needs, energy savings and payback periods reflect those of solar PV panels without feed-in tariffs.

These appraisals and scenarios are then subjected to a participatory review in expert workshops to ensure that they are as realistic as possible. Lists of all of the measures considered in the analysis are presented in Table 1. Lists of all of the participants in the expert workshops are presented in Appendix A.

Table 1: Lists of the low carbon measures considered.

Energy	Retrofitting coal generation (6045 MW), wind generation (450 MW), solar PV (450 MW), solar PV (900 MW)
Domestic	Air conditioners – energy efficiency standards; banning incandescent light bulbs; biomass boilers; entertainment appliances – standby; fuel switching (coal to LPG, cow-dung cake to LPG); green building standards; kitchen appliances – energy efficiency standards; raising thermostat 1˚C; retrofitting with mineral wool and fibreglass urethane; setting LED targets; solar lamps for outdoor lighting; solar photovoltaic panels with and without FiT; solar water heaters with and without FiT; turning off lights; washing machines – energy efficiency standards; water heaters – energy efficiency standards.
Commercial buildings	Air conditioners – energy efficiency standards; banning incandescent light bulbs; computers – energy management; copiers – energy management; elevators and escalators – energy efficiency standards; green building standards; monitors – energy management; printers – energy management; raising thermostat 1˚C; retrofitting with mineral wool and fibreglass urethane; setting LED targets; solar photovoltaic panels with and without a feed-in tariff (FiT); turning off lights.
Industry*	Benchmarking; energy management systems; process integration; efficient motor systems; boiler upgrades; furnace upgrades; lighting upgrades; HVAC (heating, ventilation and air conditioning) upgrades; fuel switching; renewables; power recovery; co-generation; feedstock change; product changes; material efficiencies.
Transport	Metro East West Expansion; Metro Phase 2 Expansion; high quality Bus Rapid Transit (42.5km); tram network recapitalisation and roadway designation;cycling infrastructure; car vehicle efficiency standards; parking demand management; Light Rail Transit line; CNG bus replacement.
Waste	Improved recycling; gasification; refuse-derived fuels; landfill gas flaring; windrow composting; anaerobic digestion; in-vessel composting; incineration; sanitary semi-aerobic landfills.

**Industrial measures are based on the groupings of 62 sector specific measures into broader categories to aid analysis and presentation. Full details of the sector specific measures are included in Chapter 4 and in Appendices C and D.*

Assessment of the scope for deployment.

We evaluate the potential scope for deploying each of the measures in the various sectors in Kolkata in the period to 2025. We calculate deployment not only for the sectors as a whole, but also for sub-sectors, taking into account for example the scope for change in households with different income levels and forms of energy consumption, or the scope for an option to be adopted in a particular industrial sub-sector.

Based on stakeholder consultations, we develop realistic and ambitious rates of deployment – with realistic rates being based on readily achievable levels of up-take, and ambitious rates assuming rates of deployment or take-up that could be achieved if supporting policies and favourable conditions were in place. These assessments take into account the lifespans and rates of renewal of existing measures that could be replaced with more energy efficient or lower carbon alternatives, and also rates of change and growth in the relevant sectors of the city.

Again, we subject our assessments of the scope for/ rates of deployment to participatory review in expert workshops to ensure that they are as realistic as possible.

Aggregation, assessment of investment needs and opportunities.

We draw 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 influence of each measure across the different sectors of the city as a whole. This allows us to understand overall investment needs and paybacks, as well as impacts on energy supply and demand in the different sectors in the city. It also allows us to generate league tables of the most cost and carbon effective measures that could be adopted both in each sector and across the city as a whole.

More detailed explanations of the data sources, methods and assumptions used for each sector are presented in Appendix B.

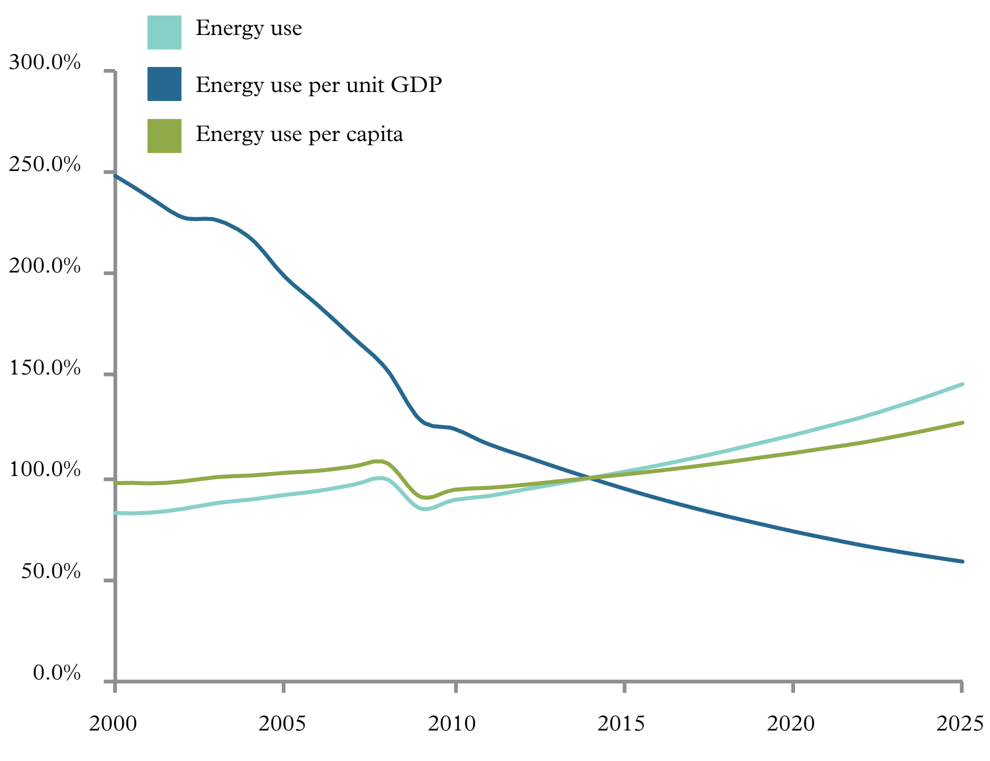
Chapter 3.
The Key Findings for Kolkata

The Changing Context and the Impacts of Business as Usual Trends

We find that Kolkata's GDP in 2014 was INR 1.84 trillion (US$31.7 billion), if recent trends continue we forecast that they will grow to INR 4.4 (US$75.2 billion) by 2025. We therefore find that per capita incomes in Kolkata were INR 125,109 (US$2,139) in 2014 and that with projected rates of economic and population growth they will grow to INR278,710 (US$4,766) by 2025. We also find that the total energy bill for Kolkata in 2014 was INR 169.2 billion (US$2.9 billion), which equates to 9.1% of GDP. In other words, 9.1% of all income earned in Kolkata is currently spent on energy.

Business as usual trends in Kolkata show a rapid decoupling of economic output, energy use and carbon emissions between 2000 and 2025 (see Fig.1). However, GDP and energy demand per capita are both rising steadily, while the population of Kolkata is also growing. These effects are offsetting these improvements in energy intensity and leading to a net increase in energy use.

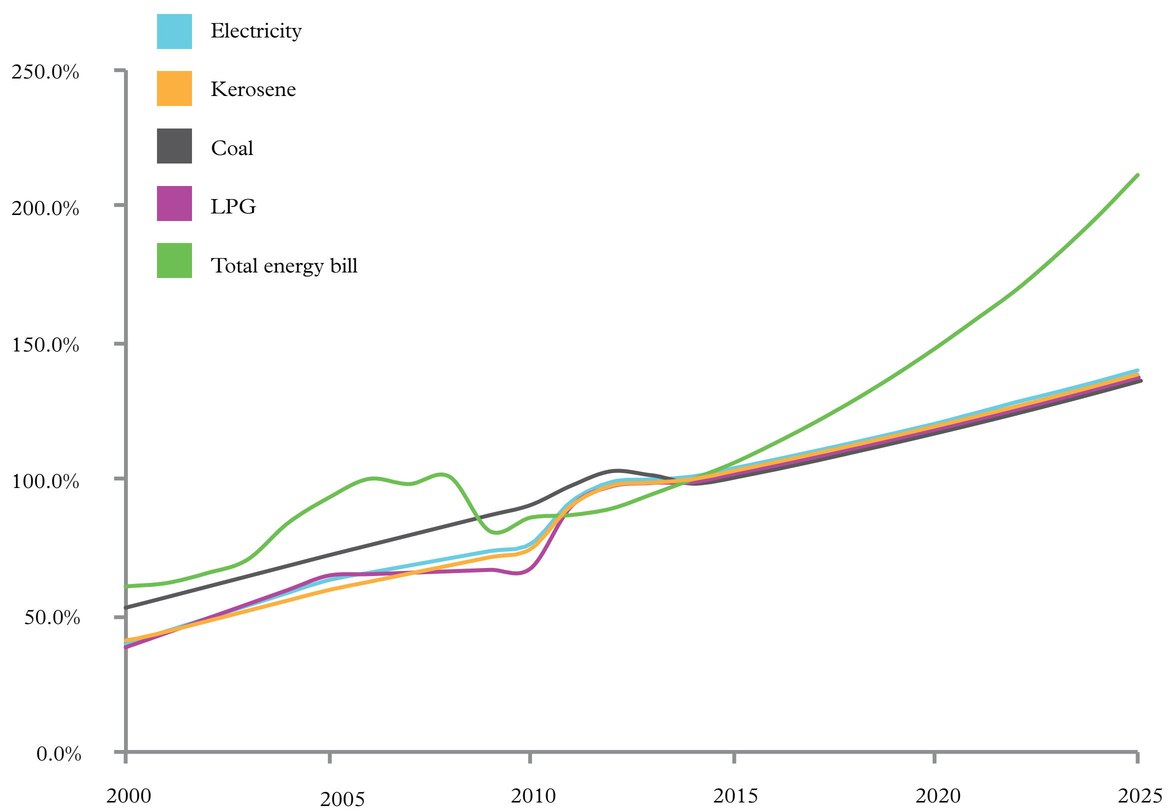
Figure 1: Indexed energy use – total, per unit of GDP and per capita.



We have assumed an increase of 3% per annum for real energy prices. The rising real energy prices combined with increasing energy consumption means that the total energy bill for Kolkata will more than double its 2014 level by 2025 in a business as usual scenario.

The emissions intensity of energy production is projected to remain largely constant until 2025, but increasing energy efficiency in the wider economy means that the emissions produced per unit of GDP will fall dramatically between 2000 and 2025. This is significant because this is the index that India isusing in their national carbon targets in international negotiations. It is important to note that, despite declining emission intensity per unit of GDP, rapid economic growth still means that emissions per capita and total emissions are continuing to rise. Ina business as usual scenario, total emissions from Kolkata are therefore forecast to increase by 54.0% on 2012 levels by 2025.

Figure 2: Indexed energy prices and total energy bill.



For Kolkata, business as usual trends will lead total energy consumption to rise by 44.1% from 41.6 TWh in 2014 to a forecast level of 56.0 TWh in 2025 (see Fig. 4).

When combined with increasing real energy prices, this leads to the total expenditure on energy to increase by 111.6% from INR 169.2 billion (US$2.9 billion) in 2014 to a forecast level of INR 357.9 billion (US$6.1 billion) in 2025 (see Fig. 5).

When combined with relatively stable levels of carbon emissions per unit of energy consumed, this leads to carbon emissions attributed to domestic consumption increasing by 54.0% from 24.9 MtCO_2-e in 2014 to a forecast level of 37.9 MtCO_2-e in 2025 (see Fig. 6).

Figure 3: Indexed total emissions per unit of energy, per unit of GDP and per capita.

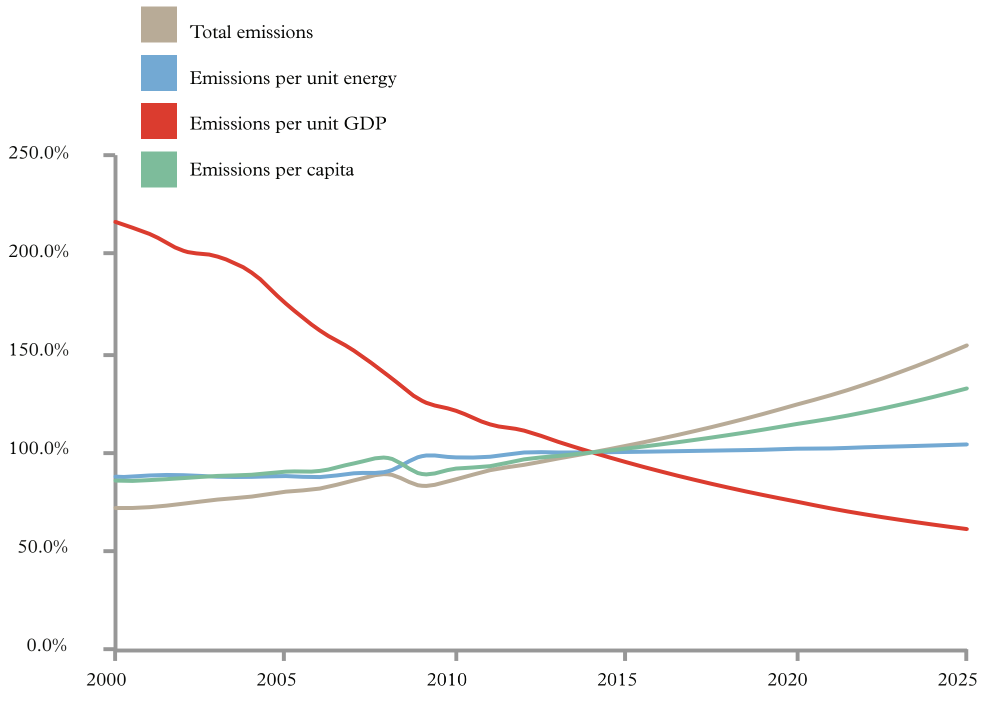


Figure 4: Energy consumption in Kolkata (TWh) between 2000 and 2025.

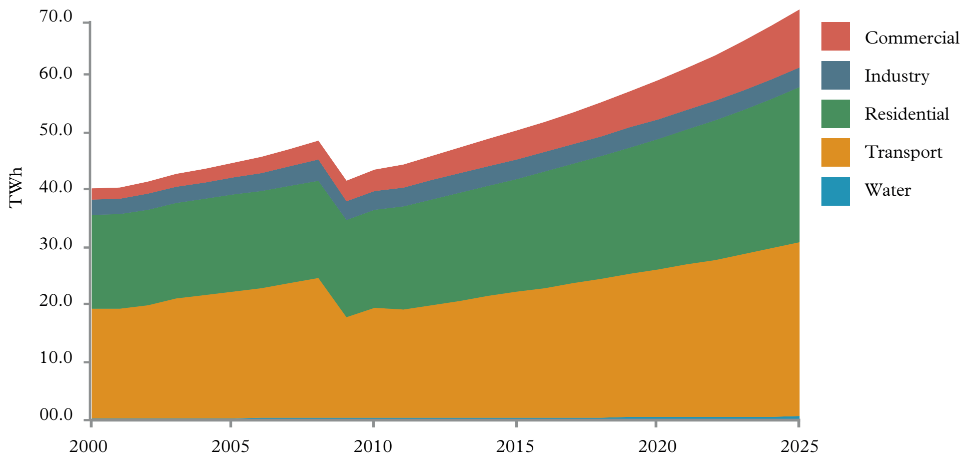


Figure 5: The energy bill for Kolkata (INR billions) between 2000 and 2025.

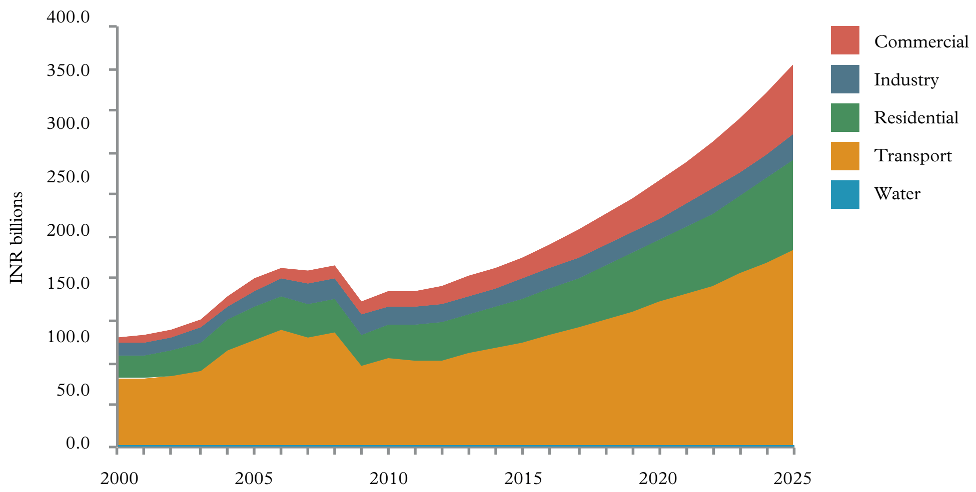
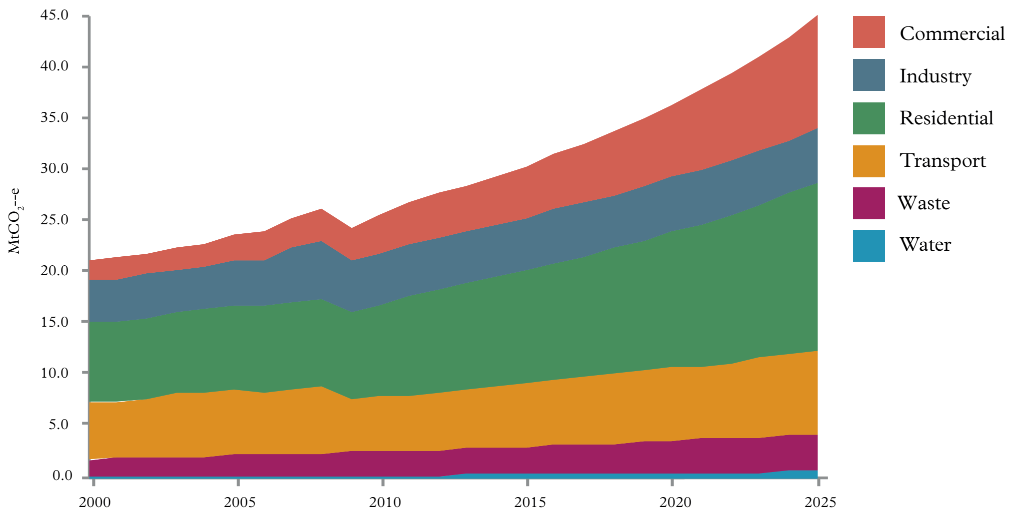


Figure 6: Emissions from Kolkata ($MtCO_2$-e) between 2000 and 2025.



Carbon Development

We find that - compared to business as usual trends – the KMA could reduce its carbon emissions by 2025 by:

- 20.7% through cost effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require an investment of INR 119.3 billion (US$2.0 billion), generating annual savings by reducing energy bills by INR 30.4 billion (US$520.7 million), paying back the investment in 3.9 years and generating annual savings for the lifetime of the measures.
- 22.1% if, as well as the above investments, cost effective investments in the electricity sector were made that could more than pay for themselves on commercial terms over their lifetime. This would require an investment of INR 39.7 billion (US$ 679.0 billion), generating annual savings of INR 18.2 billion (US$ 311.8 million), paying back the investment in 2.2 years and generating annual savings across West Bengal for the lifetime of the measures.
- 35.9% with cost neutral measures that could be paid for by re-investing the income generated from cost-effective measures. This would require an investment of INR 205.6 billion (US$ 3.6 billion), generating annual cost savings of INR 33.5 billion (US$ 573.6 million), paying back the investment in 6.2 years and generating annual savings for the lifetime of the measures.
- 38.7% with cost neutral measures in the electricity sector that could be paid for by re-investing the income generated from cost-effective measures. This would require an investment of INR 210.4 billion (US$ 3.6 billion), generating annual cost savings of INR 27.0 billion (US$ 462.0 million), paying back the investment in 7.9 years and generating annual savings across West Bengal for the lifetime of the measures.
- 43.5% with the exploitation of all of the realistic potential of the different measures with carbon saving potential. This would require an investment of INR 473.8 billion (US$8.4 billion), generating annual savings of INR 60.1 billion (US$1.1 billion), paying back the investment in 7.9 years and generating annual savings for the lifetime of the measures.

The impacts of all of these levels of change are shown in Figures 7 and 8 on the next page.

Figure 7: Emissions from Kolkata under six different scenarios, as a function of 2012 emissions, between 2000 and 2025.

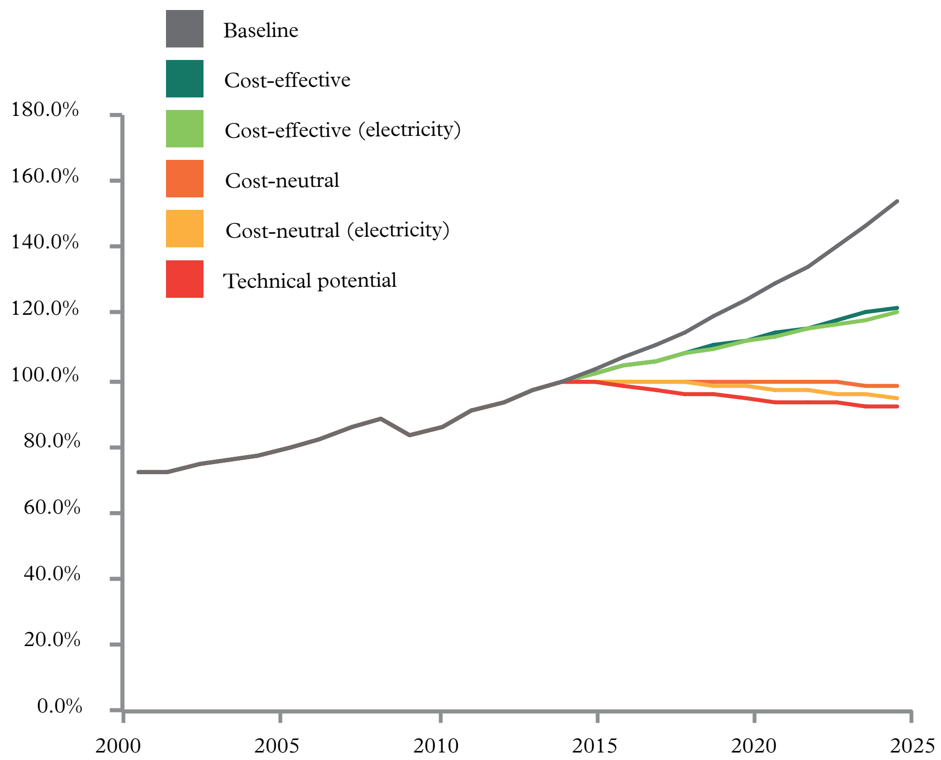
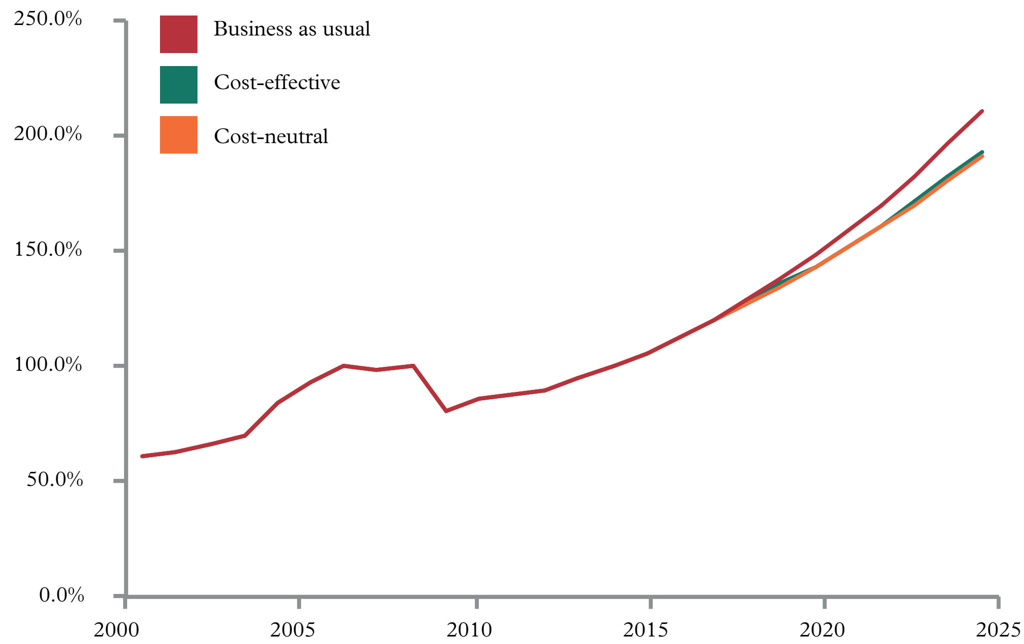


Figure 8: Energy bills for Kolkata under three different investment scenarios, as a function of 2014 emissions, between 2000 and 2025.



Sector Focus

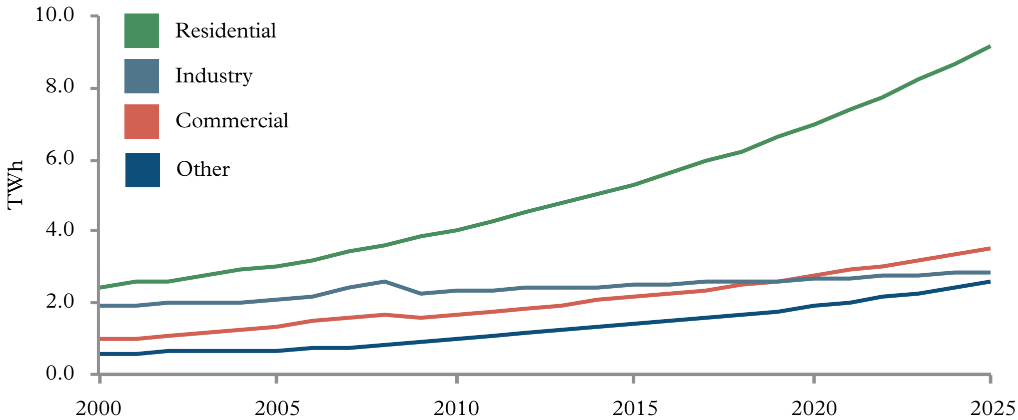
The Electricity Sector

The Changing Context and the Impacts of Business as Usual Trends

For the electricity sector, background trends suggest substantial growth in electricity consumption, dominated by the residential sector. This leads energy consumption to rise by 66.8% from 10.8 TWh in 2014 to a forecast level of 18.1 TWh in 2025 (see Fig. 9).

When combined with relatively stable levels of carbon emissions per unit of energy consumed, this leads to carbon emissions from the electricity sector increasing by 60.6% from 16.5 $MtCO_2$-e in 2014 to a forecast level of 27.8 $MtCO_2$-e in 2025 in a business as usual scenario.

Figure 9: Electricity consumption in Kolkata (TWh) between 2000 and 2025.



The Potential for Carbon Reduction – Investments and Returns

We find that – compared to 2014 – these business as usual trends in carbon emissions from the electricity sector could be reduced by:

- 11.6% through cost effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require an investment of INR 39.7 billion (US$679 million), generating annual savings of INR 18.2 billion (US$311.8 million), paying back the investment in 2.2 years but generating annual savings for the lifetime of the measures.
- 17.6% with cost neutral measures that could be paid for by re-investing the income generated from all cost-effective measures. This would require an investment of INR 210.4 billion (US$3.6 billion), generating annual savings of INR 27.0 billion (US$462 million), paying back the investment in 7.9 years but generating annual savings for the lifetime of the measures.

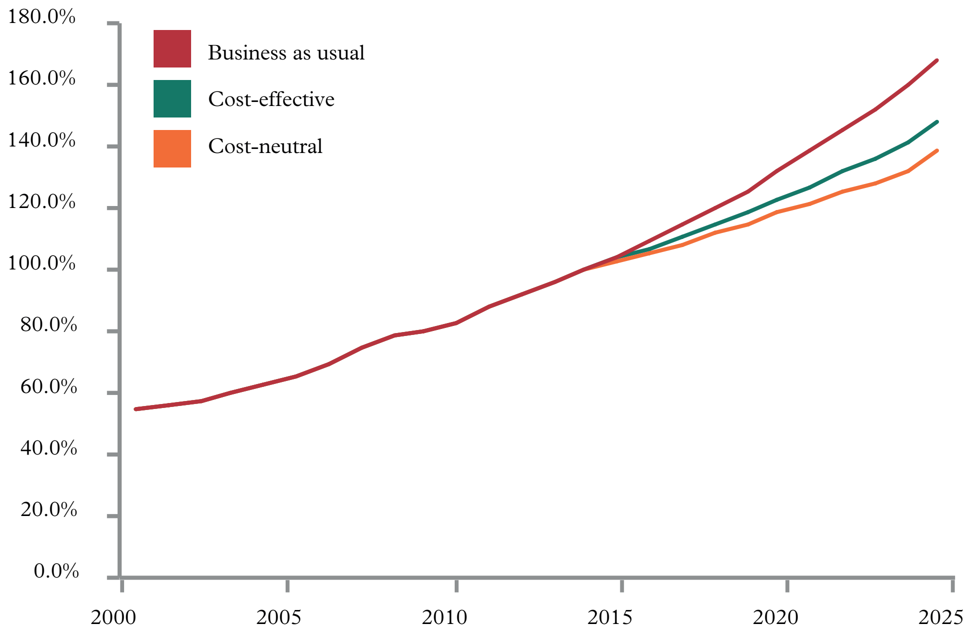
Table 2:
League table of the most cost-effective measures for the electricity sector.

Rank:	Measure:	INR/ tCO_2-e	USD/ tCO_2-e
1	Coal retrofit (6045MW)	-4,155	-71
2	Solar PV (900 MW)	1,024	18
3	Solar PV (450 MW)	1,408	24
4	Wind (450 MW)	1,419	24

Table 3:
League table of the most carbon-effective measures for the electricity sector.

Rank:	Measure:	$ktCO_2$-e
1	Coal retrofit (6045MW)	61,435
2	Solar PV (900 MW)	14,083
3	Wind (450 MW)	8,450
4	Solar PV (450 MW)	7,041

Figure 10: Emissions from the electricity sector under three different scenarios, as a function of 2014 emissions, between 2000 and 2025 .



Sector Focus

The Domestic Sector

The Domestic Sector

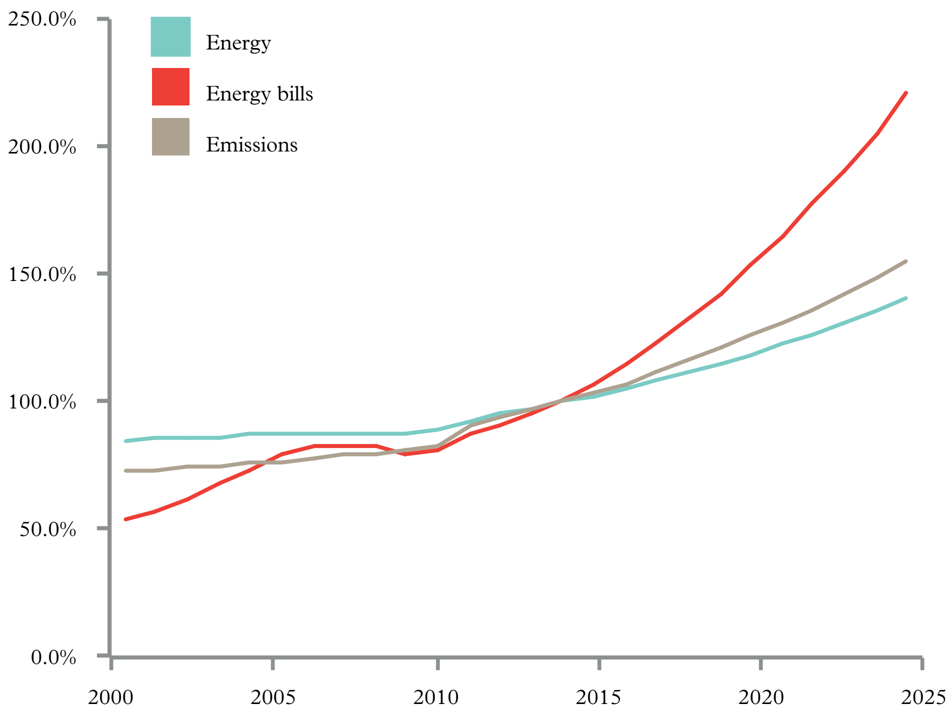
The Changing Context and the Impacts of Business as Usual Trends

For the domestic sector, background trends suggest substantial growth both in the number of households and in the average levels of energy consumption per household. These combined trends lead domestic sector energy consumption to rise by 40.7% from 16.5 TWh in 2014 to a forecast level of 23.3 TWh in 2025 (see Fig. 11).

When combined with increasing real energy prices, this leads to the total spend from the domestic sector on energy to increase by 89.3% from INR 38.1 billion (US$544 million) in 2014 to a forecast level of INR 72.1 billion (US$ 1.15 billion) in 2025.

When combined with relatively stable levels of carbon emissions per unit of energy consumed, this leads to carbon emissions attributed to domestic consumption increasing by 55.4% from 9.1 MtCO_2-e in 2014 to a forecast level of 14.0 MtCO_2-e in 2025.

Figure 11: Domestic sector: indexed energy use, energy bills and emissions.

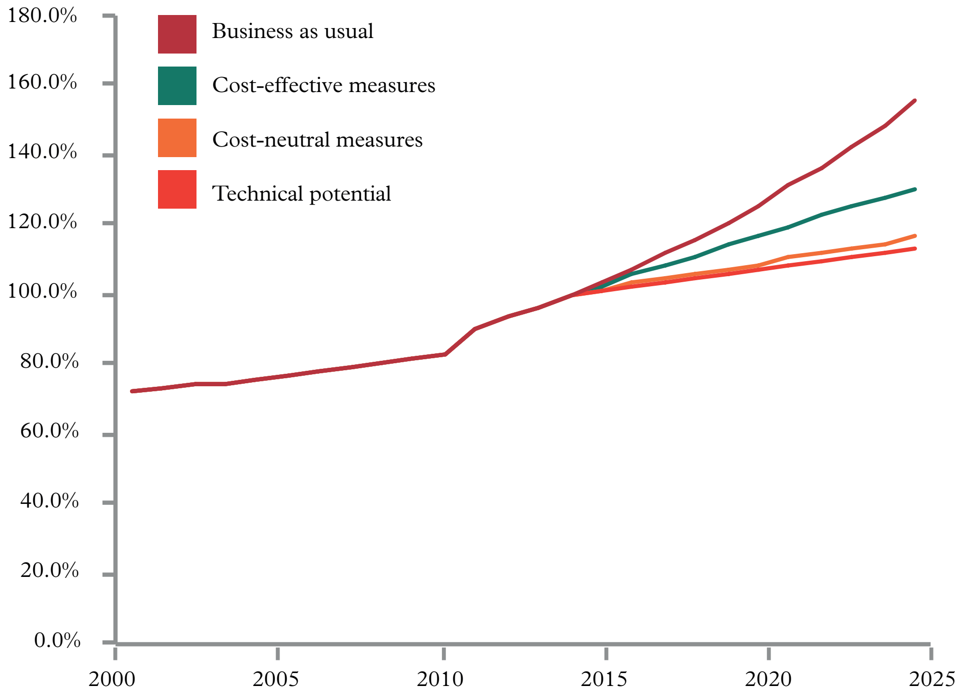


The Potential for Carbon Reduction – Investments and Returns

We find that for the domestic sector – compared to 2014 – these business as usual trends in carbon emissions could be reduced by:

- 26.4% through cost effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require an investment of INR 13.5 billion (US$230.9 million), generating annual savings of INR 5.5 billion (US$94.1 million), paying back the investment in 2.4 years and generating annual savings for the lifetime of the measures.
- 41.7% with cost neutral measures that could be paid for by re-investing the income generated from all cost-effective measures. This would require an investment of INR 38.8 billion (US$663.5 million), generating annual savings of INR 6.5 billion (US$111.2 million), paying back the investment in 6.0 years and generating annual savings for the lifetime of the measures.
- 45.1% with the exploitation of all of the realistic potential of the different measures with carbon saving potential. This would require an investment of INR 45.2 billion (US$ 772.2 million), generating annual savings of INR 6.4 billion (US$ 108.9 million), paying back the investment in 7.1 years and generating annual savings for the lifetime of the measures. These figures are based on the optimistic deployment scenarios and do not include the revenue from feed-in tariff schemes.

Figure 12: Emissions from the domestic sector in four different investment scenarios, as a function of 2014 emissions, between 2000 and 2025.



Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Table 4: League table of the most cost-effective measures for the domestic sector.

Rank:	Measure:	INR/ tCO_2-e	USD/ tCO_2-e
1	Solar water heating with FiT	-5,521	-94
2	4kWp solar PV panel with FiT	-4,963	-85
3	Banning incandescent light bulbs	-3,308	-57
4	Raising thermostat 1˚C	-2,488	-43
5	Entertainment appliances - standby	-2,461	-42
6	Air conditioner - EE Standard 1	-2,333	-40
7	Air conditioner - EE Standard 2	-2,259	-39
8	4kWp solar PV panel	-2,218	-38
9	Turning off lights	-2,113	-36
10	Green Building Standard 1 (40% of new households from 2015)	-2,036	-35
11	Green Building Standard 2 (20% of new households from 2015)	-2,036	-35
12	Water heater - EE Standard 2	-1,855	-32
13	Water heater - EE Standard 1	-1,845	-32
14	Setting LED target of 25%	-1,841	-31
15	Solar water heating	-1,794	-31
16	Entertainment appliances - EE Standard 1	-1,731	-30
17	Entertainment appliances - EE Standard 2	-1,572	-27
18	Retrofitting mineral wool insulation	-556	-10
19	Retrofitting fibreglass urethane insulation	-452	-8
20	Refrigerator - EE Standard 2	-286	-5
21	Solar lamps for outdoor lighting	-2	0
22	Refrigerator - EE Standard 1	354	6
23	Washing machine - EE Standard 1	602	10
24	Fuel switching - coal to LPG	1,685	29
25	Washing machine - EE Standard 2	1,710	29
26	Fuel switching - cow-dung cake to LPG	5,902	101

Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Table 5: League table of the most carbon-effective measures for the domestic sector.

Rank:	Measure:	$ktCO_2$-e
1	Air conditioner - EE Standard 2	6,003
2	Retrofitting fibreglass urethane insulation (20% of existing households by 2025)	4,989
3	Air conditioner - EE Standard 1	4,560
4	Entertainment appliances - EE Standard 2	3,529
5	Turning off lights	3,519
6	Entertainment appliances - EE Standard 1	2,937
7	Retrofitting mineral wool insulation (20% of existing households by 2025)	2,661
8	Retrofitting fibreglass urethane insulation (10% of existing households by 2025)	2,494
9	Water heater - EE Standard 2	2,205
10	Entertainment appliances - standby	1,710
11	Banning incandescent light bulbs	1,426
12	Retrofitting mineral wool insulation (10% of existing households by 2025)	1,330
13	Raising thermostat 1˚C	1,174
14	Water heater - EE Standard 1	938
15	4kWp solar PV panel with FiT (10MW by 2025)	887
16	4kWp solar PV panel (10MW by 2025)	887
17	Solar water heating with FiT (10% of households by 2025)	852
18	Solar water heating (10% of households by 2025)	852
19	Refrigerator - EE Standard 2	617
20	4kWp solar PV panel (5MW by 2025)	444
21	Solar water heating (5% of households by 2025)	426
22	Setting LED target of 25%	423
23	Fuel switching - coal to LPG	190
24	Washing machine - EE Standard 2	174
25	Washing machine - EE Standard 1	136
26	Refrigerator - EE Standard 1	123
27	Green Building Standard 2 (40% of new households from 2015)	119
28	Green Building Standard 1 (40% of new households from 2015)	60
29	Solar lamps for outdoor lighting (100% of outdoor lamps sold)	45
30	Green Building Standard 2 (20% of new households from 2015)	30
31	Green Building Standard 1 (20% of new households from 2015)	30
32	Solar lamps for outdoor lighting (50% of outdoor lamps sold)	22
33	Fuel switching - cow-dung cake to LPG	0.5

Sector Focus

The Commercial Buildings Sector

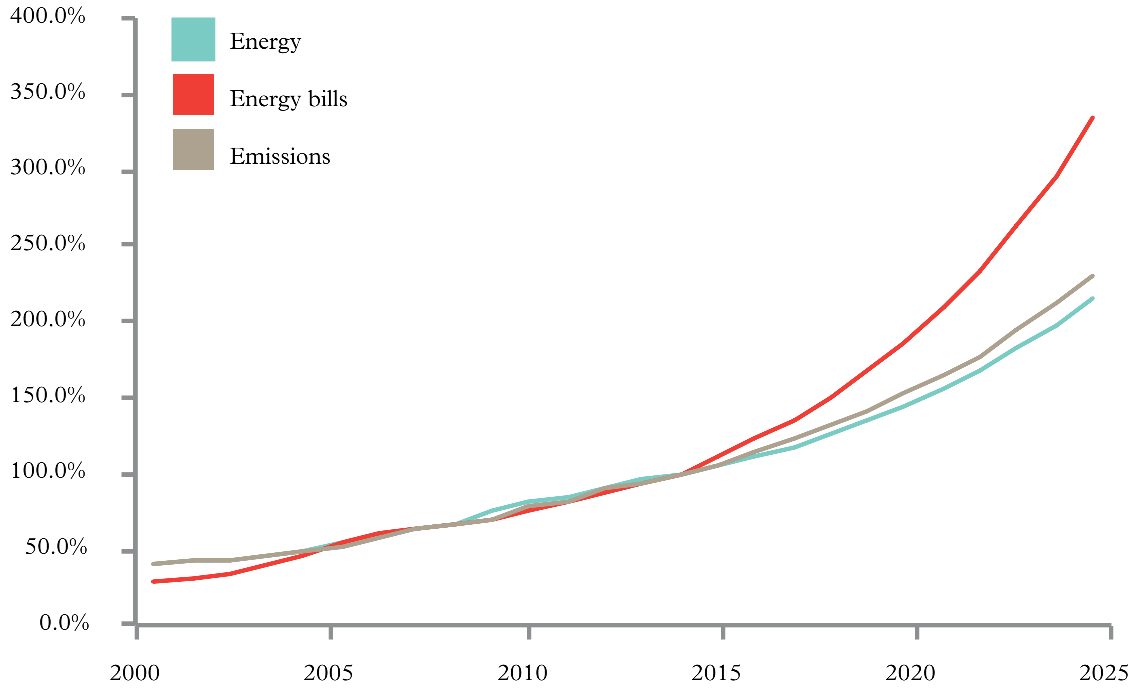
The Changing Context and the Impacts of Business as Usual Trends

For the commercial sector, background trends suggest substantial growth both in commercial floor space and in the average levels of energy consumption in each commercial building. These combined trends lead commercial sector energy consumption to rise by 114.7% from 4.1 TWh in 2014 to a forecast level of 8.7 TWh in 2025 (see Fig. 13).

When combined with increasing real energy prices, this leads to the total expenditure on energy by the commercial sector to increase by 190.1% from INR 16.4 billion (US$211 million) in 2014 to a forecast level of INR 47.5 billion (US$760 million) in 2025.

When combined with relatively stable levels of carbon emissions per unit of energy consumed, this leads to carbon emissions attributed to domestic consumption increasing by 130.7% from 4.1 $MtCO_2$-e in 2014 to a forecast level of 9.3 $MtCO_2$-e in 2025.

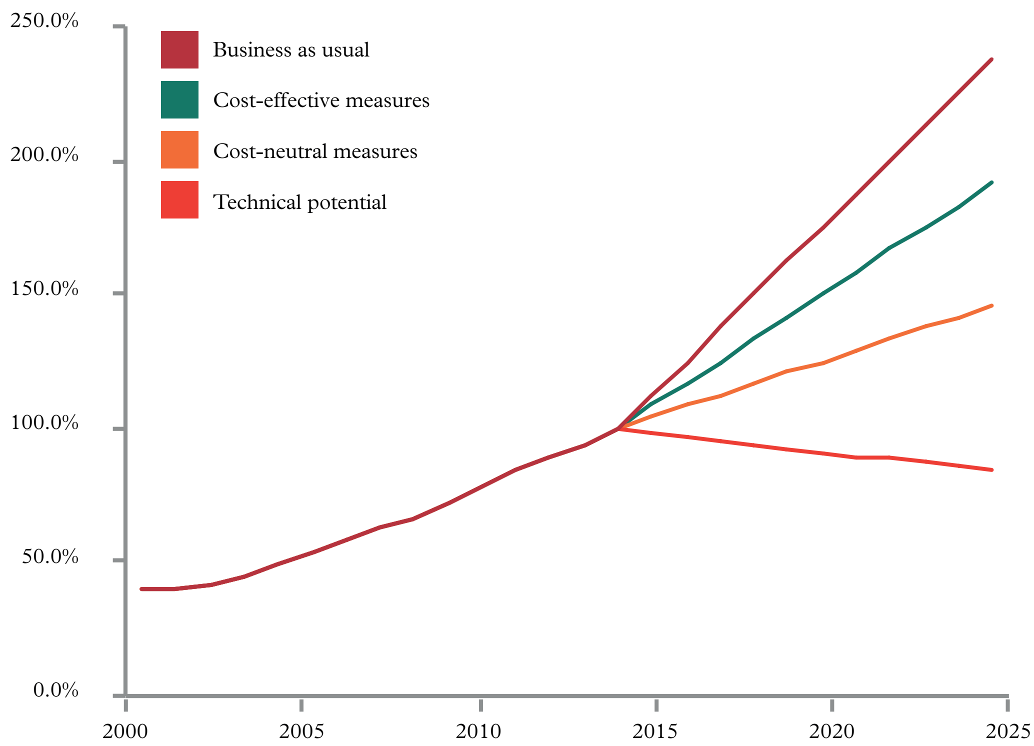
Figure 13: Commercial sector: indexed energy use, bills and emissions.



We find that for the commercial buildings sector – compared to 2014 – these business as usual trends in carbon emissions could be reduced by:

- 19.3% through cost effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of INR 39.6 billion (US$676.8 million), generating annual savings of INR 5.6 billion (US$95.8 million), paying back the investment in 7.0 years but generating annual savings for the lifetime of the measures.
- 19.4% through cost-neutral investments that could be paid for by re-investing the income generated from the cost-effective measures. This would require an investment of INR 39.7 billion (US$678.6 million), generating annual savings of INR 5.6 billion (US$95.8 million), paying back the investment in 7.1 years but generating annual savings for the lifetime of the measures.
- 26.0% with the exploitation of all of the realistic potential of the different measures with carbon saving potential. This would require an investment of INR 107.9 billion (US$ 1.8 billion), generating annual savings of INR 7.8 billion (US$ 133.1 million), paying back the investment in 13.9 years and generating annual savings for the lifetime of the measures. These figures are based on the optimistic deployment scenarios and do not include the revenue from feed-in tariff schemes.

Figure 14: Emissions from the commercial buildings sector under four different investment scenarios, as a function of 2014 emissions, between 2000 and 2025.



Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Table 6: League table of the most cost-effective measures for the commercial sector.

Rank:	Measure:	IDR/ tCO_2-e	USD/ tCO_2-e
1	20kWp solar PV panel with FiT	-11,353	-194
2	Banning incandescent light bulbs	-4,674	-80
3	Electronics - energy management	-2,643	-45
4	Raising thermostat 1˚C	-2,475	-42
5	Elevators and escalators - EE Standard 1	-2,167	-37
6	Elevators and escalators - EE Standard 2	-2,167	-37
7	Air conditioner - EE Standard 2	-1,307	-22
8	Air conditioner - EE Standard 1	-1,260	-22
9	Setting LED target of 25%	-3	0
10	Turning off lights - BAU	-3	0
11	Green Buildings Standard 1	-2	0
12	Green Buildings Standard 2	-2	0
13	20kWp solar PV panel	24	0

Table 7: League table of the most carbon-effective measures for the commercial sector.

Rank:	Measure:	$ktCO_2$-e
1	Green Buildings Standard 2 (100% of new buildings)	6,768
2	Air conditioner - EE Standard 2	3,688
3	Green Buildings Standard 1 (100% of new buildings)	3,384
4	Green Buildings Standard 2 (50% of new buildings)	3,384
5	Air conditioner - EE Standard 1	1,844
6	Electronics - energy management	1,830
7	Green Buildings Standard 1 (50% of new buildings)	1,692
8	Turning off lights	999
9	Raising thermostat 1˚C	548
10	Banning incandescent light bulbs	477
11	Elevators and escalators - EE Standard 2	469
12	Elevators and escalators - EE Standard 1	235
13	Setting LED target of 25%	178
14	20kWp solar PV panel (80% of buildings)	15
15	20kWp solar PV panel with FiT (80% of buildings)	15
16	20kWp solar PV panel (40% of buildings)	8
17	20kWp solar PV panel with FiT (40% of buildings)	8

Sector Focus

The Industrial Sector

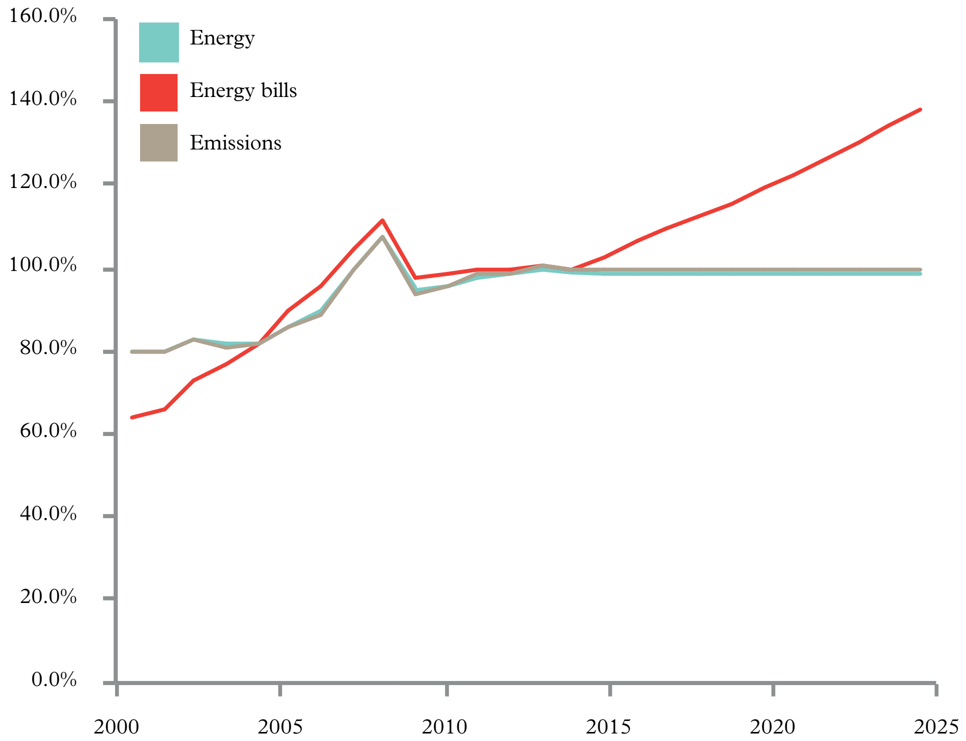
The Changing Context and the Impacts ofBusiness as Usual Trends

For the industrial sector, background trends show that industrial energy use peaked in 2008 and has declined since. This is because current government policy is preferentially locating heavy industry outside of the KMA. This explains why energy use in industry appears to have plateaued at 2.9 TWh (see Fig. 15).

When combined with increasing real energy prices, this leads to the total spend from the industrial sector on energy to increase by 38.2% from INR 17.5 billion (US$298.8 million) in 2014 to a forecast level of INR 24.2 billion (US$413.1 million) in 2025.

When combined with relatively stable levels of carbon emissions per unit of energy consumed, this leads to carbon emissions attributed to industrial consumption staying roughly constant at 4.45 $MtCO_2$-e.

Figure 15: Industrial sector: indexed energy use, bills and emissions.



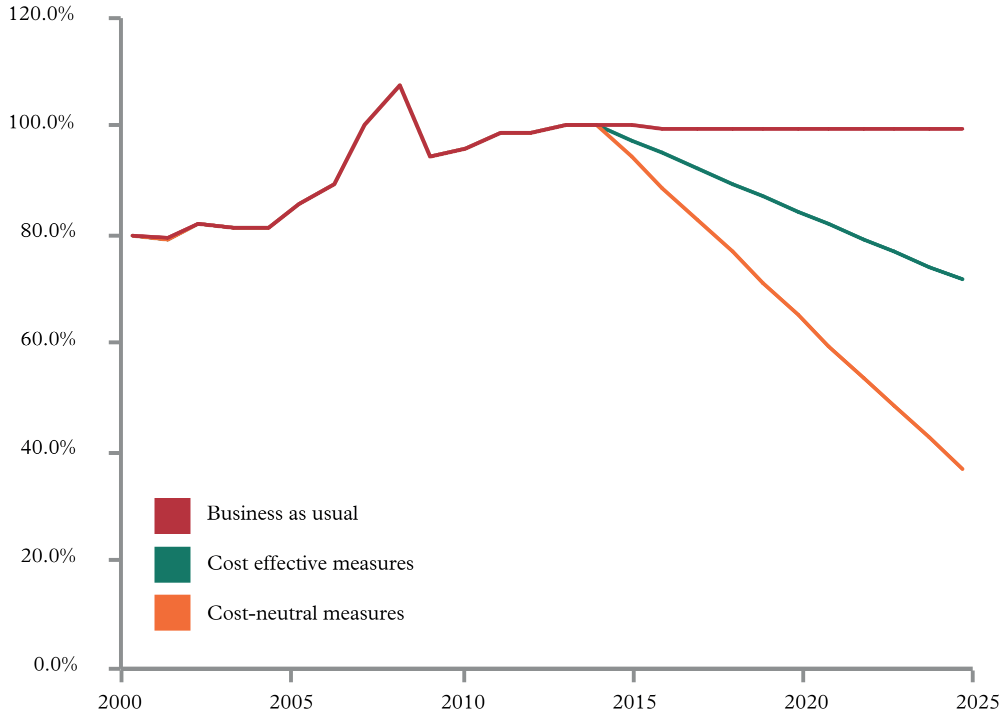
The Potential for Carbon Reduction – Investments and Returns

We find that for the industrial sector these business as usual carbon emissions could be reduced by:

— 27.8% through cost effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require an investment of INR 6.3 billion (US$107.7 million), generating annual savings of INR 3.1 billion (US$53.0 million), paying back the investment in 2.0 years but generating annual savings for the lifetime of the measures.

— 63.1% with the exploitation of all of the realistic potential of the different measures with carbon saving potential. This would require an investment of INR 9.6 billion (US$ 164 .2 million), generating annual savings of INR 4.1 billion (US$70.1 million), paying back the investment in 2.3 years but generating annual savings for the lifetime of the measures.

Figure 16: Emissions from the industrial sector under three different investment scenarios, as a function of 2014 emissions, between 2000 and 2025.



Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Table 8: League table of the most cost-effective measures for the industry sector.

Rank:	Subsector	Measure:	INR/ tCO_2-e	USD/ tCO_2-e
1	Basic metals & fabrication	Waste heat recovery (oil-fired melting)	-22390	-383
2	Paper, wood, printing and products	Pressurised head box	-21770	-372
3	Basic metals & fabrication	Wood gasifier (oil-fired melting)	-20141	-344
4	Basic metals & fabrication	Waste heat recovery (coke-fired melting)	-16335	-279
5	Chemicals, rubber and plastics	Insulation of cyclone system in spray dryers	-14634	-250
6	Basic metals & fabrication	Induction furnace for melting	-14591	-249
7	Basic metals & fabrication	Wood gasifier (coke-fired melting)	-14506	-248
8	Chemicals, rubber and plastics	Installation of exhaust gas heat recovery system in spray dryer	-13909	-238
9	Non-metallic	Installation of recuperator in tunnel kiln	-11435	-196
10	Non-metallic	Use of hot air of cooling zone of tunnel kiln as combustion air	-11299	-193
11	Non-metallic	Installation of low thermal mass cars in tunnel kiln for sanitary wares	-9634	-165
12	Paper, wood, printing and products	Energy efficiency improvements in process pumps	-9520	-163
13	Paper, wood, printing and products	Boiler feed water pressure drop	-9039	-155
14	Paper, wood, printing and products	Flash steam recovery	-8974	-153
15	Paper, wood, printing and products	Boiler feed water pump efficiency improvement	-8969	-153
16	Non-metallic	Use of energy efficient motor for polishing line	-8149	-139
17	Paper, wood, printing and products	Installation of screw press	-8061	-138
18	Non-metallic	Installation of natural gas turbine for electricity generation and use of exhaust flue gas of turbine in spray dryer	-7995	-137
19	Basic metals & fabrication	Energy efficient pit furnace (coke-fired melting)	-7705	-132
20	Chemicals, rubber and plastics	Matching the centre of motor axis with ball mill axis	-7341	-126
21	Paper, wood, printing and products	Installation of high consistency pulper	-6833	-117
22	Chemicals, rubber and plastics	Replacement of conventional gear system with planetary gear system in reaction vessels	-6778	-116
23	Textiles	Variable frequency drives	-6552	-112
24	Textiles	Tri-generation micro turbine	-6442	-110
25	Textiles	Energy efficient pumps	-6361	-109
26	Chemicals, rubber and plastics	Energy efficient motors	-6354	-109
27	Chemicals, rubber and plastics	Replacement of conventional V belts with flat belts in various drives	-6281	-107
28	Non-metallic	Use of hot air of final cooling of tunnel kiln	-6009	-103
29	Non-metallic	Installation of briquette fired hot air generator	-5782	-99
30	Basic metals & fabrication	Thermo couples for annealing furnace	-5724	-98
31	Basic metals & fabrication	Modified wood fired annealing furnace	-5636	-96
32	Textiles	Natural gas generator with co-generation	-5041	-86
33	Chemicals, rubber and plastics	Replacement of conventional horizontal agitator system with vertical agitator system	-4666	-80
34	Textiles	Steam based co-generation system	-4464	-76
35	Non-metallic	Installation of natural gas engine for electricity generation and use of exhaust flue gas of engine in spray dryer	-4346	-74
36	Basic metals & fabrication	Wood gasifier for annealing	-3974	-68
37	Chemicals, rubber and plastics	Improvements in hot air distribution system	-3811	-65

Table 8 continued

Rank:	Subsector	Measure:	INR/ tCO_2-e	USD/ tCO_2-e
38	Chemicals, rubber and plastics	Improving insulation of hot air generator	-3764	-64
39	Chemicals, rubber and plastics	Energy efficient hot air generator system	-3414	-58
40	Chemicals, rubber and plastics	Energy efficient wood-fired boiler	-3383	-58
41	Chemicals, rubber and plastics	Replacement of conventional tray dryer system with energy efficient tray dryer system	-3354	-57
42	Non-metallic	Improvement in kiln, spray dryer & other hot surfaces insulation	-3076	-53
43	Chemicals, rubber and plastics	Replacement of manual filter press with mechanical filter press	-2911	-50
44	Chemicals, rubber and plastics	Replacement of conventional filter press (recess plates) with membrane filters press	-2892	-49
45	Chemicals, rubber and plastics	Replacement of conventional wood fired tray dryer system with solar tray dryer system	-2682	-46
46	Non-metallic	Energy efficiency improvements in motors of agitation section	-2540	-43
47	Textiles	Heat recovery system	-2440	-42
48	Textiles	Online flue gas monitoring system	-2266	-39
49	Textiles	Energy efficient boilers	-1478	-25
50	Non-metallic	Preheating of input slurry of spray dryer through solar energy	-1474	-25
51	Non-metallic	Implementation of ON - OFF system (10 minutes ON and 5 minutes OFF) for agitation motors	-1342	-23
52	Chemicals, rubber and plastics	Replacement of conventional wood fired hot air generator system with energy efficient gas fired hot air generator system	-1017	-17
53	Paper, wood, printing and products	Boiler fans efficiency improvements	-801	-14
54	Paper, wood, printing and products	Boiler efficiency improvement	-796	-14
55	Paper, wood, printing and products	Digester blow heat recovery	-742	-13
56	Paper, wood, printing and products	Steam consumption reduction by efficient condensate evacuation	-549	-9
57	Non-metallic	Preheating of combustion air by smoke air through recuperator in ceramic tiles	-520	-9
58	Paper, wood, printing and products	Installation of pocket ventilation system	-275	-5
59	Non-metallic	Installation of variable frequency drive (VFD) in motors of agitation system	-102	-2
60	Textiles	Energy efficiency stenters	0	0
61	Non-metallic	Installation of variable frequency drive (VFD) in ball mill and blunger	52	1
62	Textiles	Pressure powered pumping packing unit	223	4

Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Table 9: League table of the most carbon-effective measures for the industry sector.

Rank:	Subsector	Measure:	$ktCO_2$-e
1	Textiles	Heat recovery system	2507
2	Non-metallic	Installation of natural gas turbine for electricity generation and use of exhaust flue gas of turbine in spray dryer	2318
3	Non-metallic	Installation of natural gas engine for electricity generation and use of exhaust flue gas of engine in spray dryer	2200
4	Textiles	Energy efficient boilers	2146
5	Non-metallic	Preheating of combustion air by smoke air through recuperator in ceramic tiles	2085
6	Textiles	Steam based co-generation system	1666
7	Textiles	Tri-generation micro turbine	1489
8	Textiles	Online flue gas monitoring system	1399
9	Textiles	Energy efficient pumps	1210
10	Paper, wood, printing and products	Boiler efficiency improvement	889
11	Non-metallic	Preheating of input slurry of spray dryer through solar energy	835
12	Textiles	Natural gas generator with co-generation	786
13	Non-metallic	Installation of briquette fired hot air generator	688
14	Non-metallic	Improvement in kiln, spray dryer & other hot surfaces insulation	646
15	Non-metallic	Installation of variable frequency drive (VFD) in ball mill and blunger	591
16	Chemicals, rubber and plastics	Energy efficient wood-fired boiler	571
17	Chemicals, rubber and plastics	Energy efficient tray dryer system	533
18	Chemicals, rubber and plastics	Replacement of conventional wood fired hot air generator system with energy efficient gas fired hot air generator system	479
19	Chemicals, rubber and plastics	Replacement of conventional filter press (recess plates) with membrane filters press	429
20	Chemicals, rubber and plastics	Replacement of conventional wood fired tray dryer system with solar tray dryer system	343
21	Paper, wood, printing and products	Digester blow heat recovery	324
22	Chemicals, rubber and plastics	Energy efficient hot air generator systems	311
23	Chemicals, rubber and plastics	Installation of exhaust gas heat recovery system in spray dryer	288
24	Paper, wood, printing and products	Boiler fans efficiency improvement	272
25	Chemicals, rubber and plastics	Replacement of manual filter press with mechanical filter press	267
26	Paper, wood, printing and products	Steam consumption reduction by efficient condensate evacuation	242
27	Textiles	Pressure powered pumping packing unit	200
28	Non-metallic	Implementation of ON - OFF system (10 minutes ON and 5 minutes OFF) for agitation motors	192
29	Chemicals, rubber and plastics	Improvements in hot air distribution system	139
30	Paper, wood, printing and products	Installation of pocket ventilation system	119
31	Non-metallic	Energy efficient motors in agitation section	117
32	Non-metallic	Installation of variable frequency drive (VFD) in motors of agitation system	98
33	Chemicals, rubber and plastics	Replacement of conventional horizontal agitator system with vertical agitator system	97
34	Chemicals, rubber and plastics	Improving insulation of hot air generator	87
35	Textiles	Energy efficiency stenters	86
36	Non-metallic	Use of energy efficient motor for polishing line	81
37	Basic metals & fabrication	Wood gasifier (coke-fired melting)	72

Table 9 continued

Rank:	Subsector	Measure:	$ktCO_2$-e
38	Textiles	Variable frequency drives	64
39	Non-metallic	Use of hot air of final cooling of tunnel kiln for preheating the input material	63
40	Basic metals & fabrication	Thermo couples for annealing furnace	57
41	Basic metals & fabrication	Wood gasifier for annealing	57
42	Chemicals, rubber and plastics	Replacement of conventional motors with energy efficient motors	56
43	Basic metals & fabrication	Induction furnace for melting	54
44	Basic metals & fabrication	Wood gasifier (oil-fired melting)	51
45	Non-metallic	Installation of low thermal mass cars in tunnel kiln for sanitary wares	43
46	Basic metals & fabrication	Modified wood fired annealing furnace	33
47	Paper, wood, printing and products	Energy efficiency improvement in process pumps	27
48	Chemicals, rubber and plastics	Replacement of conventional gear system with planetary gear system in reaction vessels	26
49	Chemicals, rubber and plastics	Matching the centre of motor axis with ball mill axis	25
50	Non-metallic	Use of hot air of cooling zone of tunnel kiln as combustion air	19
51	Non-metallic	Installation of recuperator in tunnel kiln thereby preheating combustion air through smoke air	18
52	Chemicals, rubber and plastics	Replacement of conventional V belts with flat belts in various drives	17
53	Chemicals, rubber and plastics	Insulation of cyclone system in spray dryers	16
54	Paper, wood, printing and products	Boiler feed water pump efficiency improvements	16
55	Paper, wood, printing and products	Installation of screw press	13
56	Basic metals & fabrication	Energy efficient pit furnace (coke-fired melting)	12
57	Paper, wood, printing and products	Flash steam recovery	8
58	Paper, wood, printing and products	Pressurised head box	7
59	Basic metals & fabrication	Waste heat recovery (coke-fired melting)	6
60	Basic metals & fabrication	Waste heat recovery (oil-fired melting)	4
61	Paper, wood, printing and products	Boiler feed water pressure drop reduction	4
62	Paper, wood, printing and products	Installation of high consistency pulper	2

Sector Focus

The Transport Sector

The Transport Sector

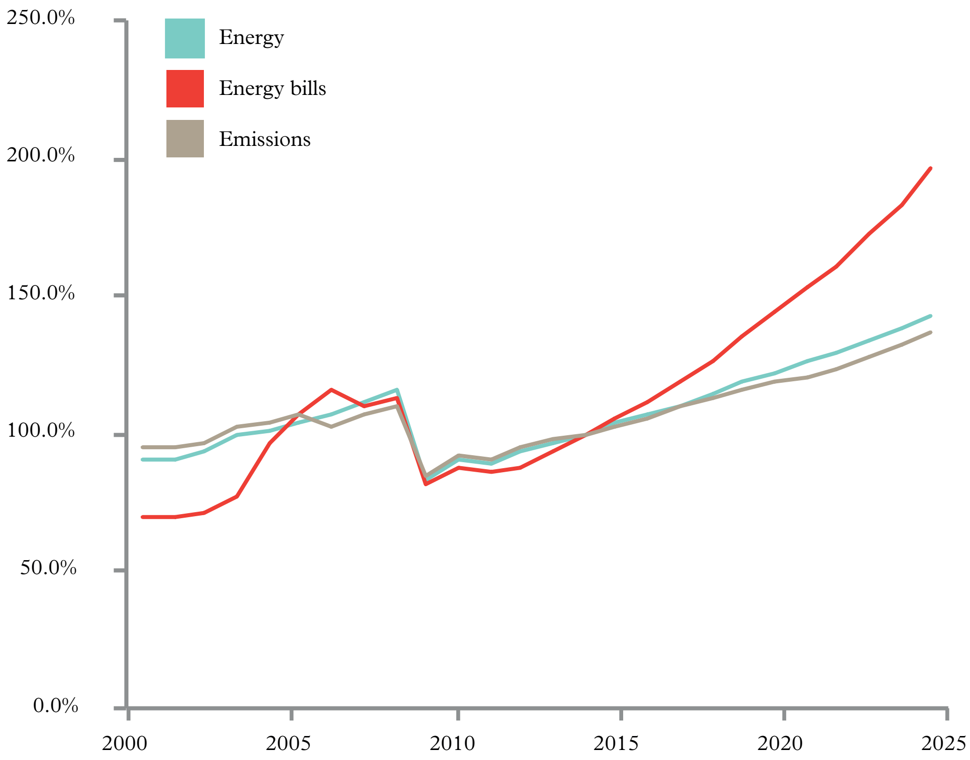
The Changing Context and the Impacts of Business as Usual Trends

For the transport sector, background trends suggest a substantial growth in the number of vehicles in Kolkata, although the trend is partially concealedby the impact of a regulatory change in 2008 which banned commercial vehicles over fifteen years old. The growth in vehicle numbers leads transport sector energy consumption to rise by 43.3% from 18.2 TWh in 2014 to a forecast level of 26.1 TWh in2025 (see Fig. 17).

When combined with increasing real energy prices, this leads to the total spend from the transport sector on energy to increase by 96.0% from INR 94.5 billion (US$1.6 billion) in 2014 to a forecast level of INR185.4 billion (US$3.2 billion) in 2025.

Although fuel efficiency is slowly increasing, the relatively high growth rate in the number of vehicles leads to carbon emissions attributed to transport increasing by 36.0% from 5.1 $MtCO_2$-e in 2014 to a forecast level of 6.9 $MtCO_2$-e in 2025.

Figure 17. Transport sector: indexed energy use, energy bills and emissions.

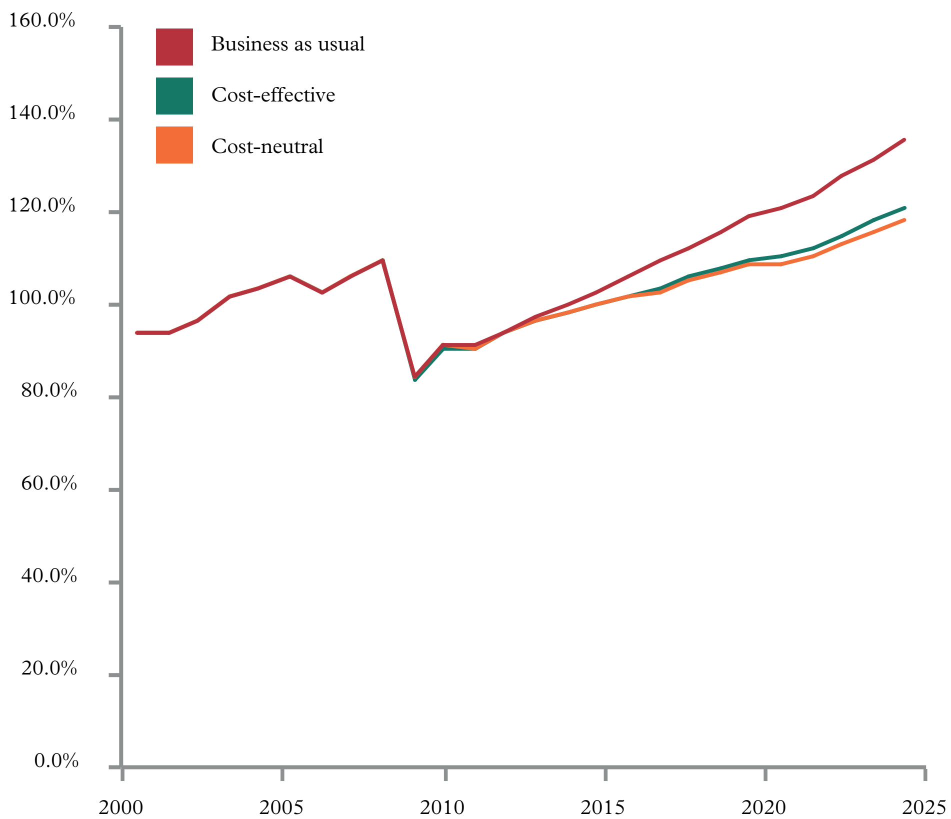


The Potential for Carbon Reduction – Investments and Returns

We find that for the transport sector – compared to 2012 – these business as usual trends in carbon emissions could be reduced by:

- 10.7% through cost effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of INR 46.8 billion (US$ 801 million), generating annual savings of INR 15.1 billion (US$ 259 million), paying back the investment in 3.1 years but generating annual savings for the lifetime of the measures.
- 13.1% with the exploitation of all of the realistic potential of the different measures with carbon saving potential. This would require an investment of INR 102.9 billion (US$1.8 billion), generating annual savings of INR 16.1 billion (US276 million), paying back the investmentin 6.4 years but generating annual savings for the lifetime of the measures.

Figure 18: Emissions from the transport sector under three different investment scenarios, as a function of 2014 emissions, between 2000 and 2025.



Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Table 10: League table of the most cost-effective measures for the transport sector.

Rank:	Measure:	IDR/ tCO_2-e	USD/ tCO_2-e
1	Parking demand management	-80,626	-1,380
2	Commercial vehicle efficiency standards (introduction 2018)	-16,117	-276
3	CNG bus replacement (introduction 2020)	-3,199	-55
4	Car vehicle efficiency standards (introduction 2014)	-250	-4
5	Tram network recapitalisation and roadway designation	11,172	191
6	BRT (42.5km)	68,230	1,167
7	Cycling infrastructure	90,675	1,552

Table 11: League table of the most carbon-effective measures for the transport sector.

Rank:	Measure:	$ktCO_2$-e
1	Commercial vehicle efficiency standards (introduction 2018)	1,933
2	CNG bus replacement (introduction 2020)	1,417
3	Parking demand management	1,138
4	BRT (42.5km)	615
5	Car vehicle efficiency standards (introduction 2014)	370
6	Tram network recapitalisation and roadway designation	287
7	Cycling infrastructure	131

Sector Focus

The Waste Sector

The Changing Context and the Impacts of Business as Usual Trends

For the waste sector, background trends suggest a steady increase in waste production per capita which, combined with population growth, is leading to substantial increases in total waste production. These trends are causing emissions from the waste sector to rise by 37.2% from 2.3 $MtCO_2$-e in 2014 to a forecast level of 3.1 $MtCO_2$-e in 2025 (see Fig. 27).

The Potential for Carbon Reduction – Investments and Returns

We find that these business as usual carbon emissions could be reduced by:

- 41.9% through cost effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require an investment of INR 13.1 billion (US$224.0 million), generating annual savings of INR 1.1 billion (US$18.8 million), paying back the investment in 11.8 years but generating annual savings for the lifetime of the measures
- 61.6% with the exploitation of all of the realistic potential of the different measures with carbon saving potential. This would require an investment of INR 14.6 billion (US$249.7 million), generating annual savings of INR 1.2 billion (US$20.5 million), paying back the investment in 12.5 years but generating annual savings for the lifetime of the measures.

Figure 19. Emissions from the waste sector ($MtCO_2$-e) between 2000 and 2025.

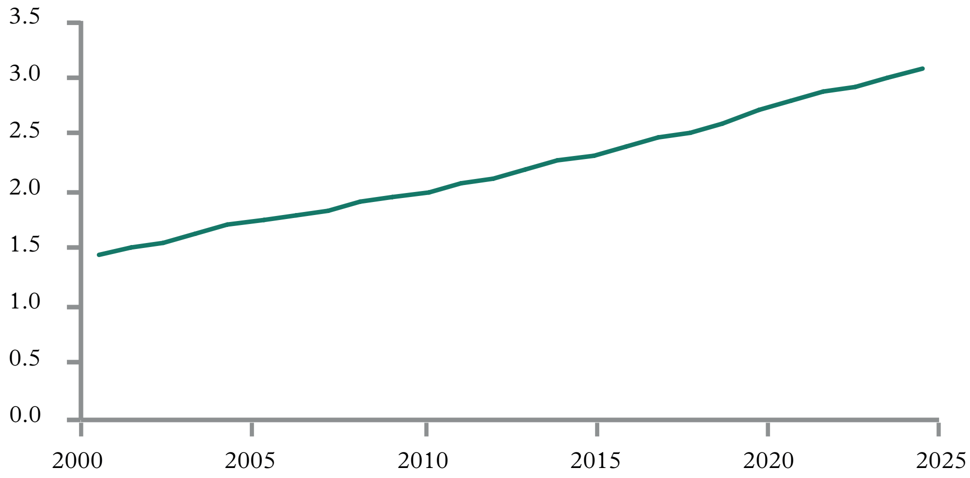


Figure 20. Emissions from waste under three different investment scenarios, as a function of 2014 emissions, between 2000 and 2025.

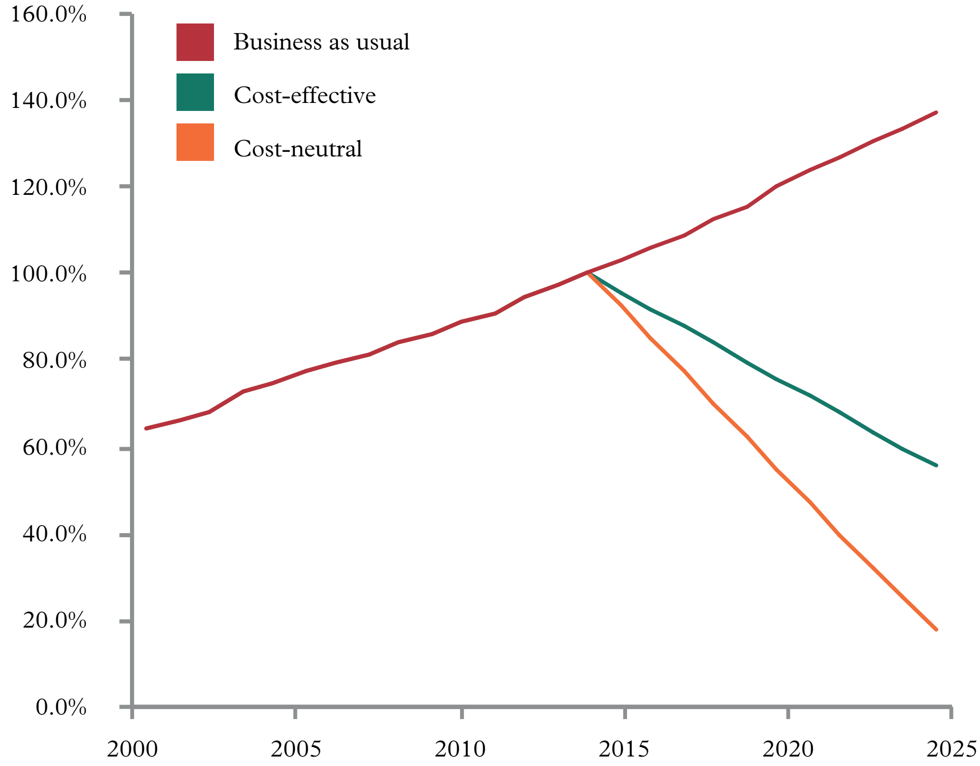


Table 12:
League table of the most cost-effective measures for the waste sector.

Rank:	Measure:	INR/ tCO_2-e	USD/ tCO_2-e
1	Improved recycling	-259.80	-4.44
2	Gasification	-135.15	-2.31
3	Refuse-derived fuel	14.44	0.25
4	Landfill gas flaring	143.34	2.45
5	Windrow composting	518.80	8.87
6	Anaerobic digestion	677.95	11.59
7	In-vessel composting	1695.56	28.99
8	Incineration	2739.47	46.84
9	Sanitary semi-aerobic landfills	4784.53	81.81

Table 13:
League table of the most carbon-effective measures for the waste sector.

Rank:	Measure:	$ktCO_2$-e
1	Gasification	1,618
2	Incineration	1,165
3	Refuse-derived fuel	860
4	Anaerobic digestion	843
5	Windrow composting	460
6	In-vessel composting	442
7	Improved recycling	226
8	Sanitary semi-aerobic landfills	153
9	Landfill gas flaring	143

Chapter 4.
Discussion

Discussion

Business as usual trends in Kolkata show a rapid decoupling of economic output, energy use and carbon emissions between 2000 and 2025. In other words, the carbon intensity of GDP is decreasing rapidly and – in relative terms - the city is already transitioning to a more energy efficient and low carbon development model. The rates of reduction in the carbon intensity of GDP are substantially higher than those targeted by the Indian government. This is worth celebrating as it means that substantial gains in human development can be achieved without a proportionate contribution to climate change.

However, population and economic growth in Kolkata is so rapid that it offsets the improvements in energy and carbon intensity. Absolute levels of energy use are projected to rise at a rate of 3.31% per annum between 2014 and 2025. This will lead to an increase in real energy bills of 111.6% to INR 357.9 billion ($US 6.1 billion) per year and of net emissions of 52.0% to 37.8MtCO_2-e per year over the same period. The major energy costs are associated with the transport sector where fuels are relatively expensive, while the most significant growth in emissions comes from the residential sector as its demand for West Bengal's highly carbon-intensive electricity increases.

These figures suggest that current rates of decoupling between economic output and energy use, while significant, will not realize the city's full potential to enhance economic competitiveness and energy security and to reduce its contribution to climate change.

This study reveals a compelling business case for large-scale investment in energy efficiency, renewable energy and low carbon development in Kolkata above and beyond these background trends. By 2025, the city can cut its emissions by 20.7% of projected emissions in the business as usual scenario through cost-effective investments that would pay for themselves on commercial terms in 3.9 years. If the profits from these investments are re-invested in low carbon measures, Kolkata can slash its emissions to35.9% relative to business as usual trends and recover its investment in 6.2 years. These low carbon measures would continue to generate annual savings throughout their lifetime.

In addition to the economic case for low carbon investment, many of these measures support broader development goals. The three most cost-effective measures identified in the study are all in the transport sector, which, if adopted, would yield improvements in air quality and congestion in the city. Industry offers the next nine most cost-effective low carbon measures: widespread adoption of these options would increase the competitiveness of the economy by reducing input costs and increasing its resilience to rising fuel prices. Small-scale solar PV and solar water heating prove to be commercially attractive in Kolkata with incentive schemes, and increased use of these renewable energy technologies would help meet the national energy policy objectives of improved energy security and energy access. The prioritised menus of the most cost-effective measures therefore highlight a wide range of win-win opportunities for different stakeholders across key sectors in Kolkata.

In other cases, this research highlights that the most carbon-effective measures are not necessarily attractive to commercial investors. This is most evident in the waste sector and electricity sector, where low carbon measures do not yield significant financial returns but do offer very significant emission reductions. These measures offer opportunities for international climate funds to achieve dramatic improvements in emissions intensity without crowding out private investment.

In the context of the small carbon footprint per capita in India and the steady fall of energy intensity of GDP, this study highlights that Kolkata is already shifting to a relatively low carbon development trajectory.

The transition could be accelerated through strategic investments in energy efficiency, renewable energy and other low carbon measures. The massive expansion of infrastructure projected for Kolkata – like most cities in fast-growing emerging economies – provides an opportunity to integrate climate considerations into urban planning at a relatively early stage. Such an approach improves both the cost- and carbon-effectiveness of most low carbon options and would significantly enhance Kolkata's efforts to transition to a more energy efficient and low carbon city.

Chapter 5.
Conclusions and Recommendations

Conclusions and Recommendations

Business as usual trends in Kolkata show a steady decline in the energy intensity of economic activity. in the city. However, absolute levels of energy use and emissions are continuing to rise steadily due to the effects of rapid population and economic growth. And energy bills are increasing steadily – which will have significant implications for economic competitiveness and for social equity.

This research reveals that there are many economically attractive opportunities to increase energy efficiency and stimulate renewable energy, which would in turn improve the economic competitiveness, energy security and carbon intensity of Kolkata. The scale of the opportunities demonstrates that preparing for climate change at an early stage of development can be attractive in commercial terms, above and beyond the immense benefits of reducing the future impacts of climate change.

Clearly the presence of such opportunities does not mean that they will necessarily be exploited. But we hope that by providing evidence on the scale and the composition of these opportunities, this report will help to build political commitment and institutional capacities for change. We also hope this report will help Kolkata to secure the investments and develop the delivery models needed to implement change. Some of the energy efficiency and low carbon opportunities could be commercially attractive whilst others may only be accessible with development assistance. Many of the opportunities would benefit from the support of enabling policies from government.

And fundamentally, we should recognise that economics is not the only discipline that has something useful to say on the transition to a low carbon economy/society. A wider analysis should also consider the social desirability of the different options, as well as issues relating to the equity, inclusivity and broader sustainability of the different pathways towards a low carbon economy and society in Kolkata.

Appendices

Appendix A:
Participants of workshops and expert consultations

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Shyamasree Dasgupta, Global Change Programme, Jadavpur University;
Siddhartha Datta, Jadavpur University;
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SP Gonchoudhuri, West Bengal Green Energy Development Corporation;
Subhashish Chatterjee, Kolkata Municipal Corporation;
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Appendix B: Data sources, methods and assumptions

The Energy Sector

The Central Electricity Authority for India and Indian Energy Statistics provide data on the carbon intensity of electricity generated in West Bengal from 2007-2011 and the operating and efficiency ratings of Indian electricity plants.[41,42]

Figures are given for the electricity generated by the Calcutta Electricity Supply Corporation (CESC) and by other West Bengal power stations. We calculate an average carbon intensity for each based on the five years of available data. This provides two carbon intensity figures for the KMA. We assume that all electricity generated by CESC is supplied to the KMA, with the remaining demand met by other West Bengal power plants. We further assume that CESC is running at capacity so the share of electricity generated from its power plants will remain constant. This allows us to calculate the carbon intensity of electricity consumed in Kolkata by weighting the carbon intensity figures for CESC and West Bengal according to the share of electricity generated by each. The growing share of electricity from other West Bengal plants, which a remarginally less carbon-intensive than those of CESC, causes the carbon intensity of electricity generation to fall slightly by 2025. In order to develop scenarios data was collected from The Central Electricity Authority for India, expert interviews, and workshops.

The Domestic Sector

Data on fuel use in the domestic sector are obtained for 1995, 2000, 2005 and 2010 from the National Sample Survey Organisation, the District Statistical Handbooks and Census India.[43,44] These sources estimate the quantity of coke, firewood and wood chips, electricity, dung cake, kerosene, coal and LPG measured in terms of consumption (kg and kWh) and expenditure (INR) per capita. These data are provided by district and are scaled to the KMA level using population data.

Using these data, we project future levels of fuel consumption and emissions by extrapolating trends from 1995 to 2010 out to 2025. Consumption and emissions from electricity, firewood and LPG increase by 3.3% , 3.4% and 5.1% per annum respectively, while the amount of coke, coal and kerosene decrease by 4.4% , 2.0% and 7.0% per annum respectively.

Electricity consumption is allocated to different appliances based on nation-wide figures from the World Bank, projected until 2031.[45] This source also provides figures on the average power consumption per hour and average hours of use of a range of different household appliances, allowing us to calculate the proportion of domestic electricity use attributable to different types of appliance. From this, and assuming that these average efficiencies and hours of use are the same in Kolkata as for India more generally, we calculate how many appliances were in use, and levels of energy consumption per appliance, in Kolkata.

We then evaluate the cost and carbon savings of more energy efficient appliances, fuel switching and the adoption of Energy Conservation Building Code (ECBC) standards for energy efficiency in new residential buildings.

For appliances, the required investment and potential returns for each type of appliance are calculated by comparing the average energy consumption of appliances in use and projected to be in use by 2025 to that of more energy efficient options. Given background rates of renewal of existing appliances, we calculate the impact of 50% of new appliance purchases being more energy efficient options. We therefore consider both increased demand for all types of appliance and higher uptake of more efficient appliances.

For fuel switching, only 6.7% of emissions in the business as usual scenario will still come from high carbon fuels (coke, coal and kerosene) in 2025, since these are already declining in use. This means that there will be limited scope to reduce emissions through further fuel switching. However, fuel switching can be increased and accelerated through workshops and advertisements. Estimates of the costs, attendance rates and impact of these promotions were provided by Jadavpur University.

For ECBC standards, to determine the costs and carbon savings, we calculate the average energy use per unit of residential floor space. Data on the residential floor space (formal and informal) in urban West Bengal was obtained from the National Sample Survey Organisation for 2001, 2002, 2005 and 2007.[46] We use data from the KMA for 2001-2010 to establish the relationship between higher GDP per capita and declining household size. The subsequent calculation uses total floor space of residential buildings divided by the total energy consumed by the domestic sector. Three scenarios were modelled for the adoption of ECBC standards. In the first scenario, all new large apartment buildings are built to ECBC standards. In the second scenario, all new large apartment buildings are built to ECBC standards and some existing blocks are retrofit to meet the standard. In the third scenario, international energy efficiency standards suitable for other types of residential buildings are applied to all new construction. In each case, ECBC targets in terms of energy use per unit of floor space were compared to the baseline figure to provide an estimate of potential energy savings.

Commercial Buildings

National data on commercial floor space and the number of commercial establishments – and forecasts of growth of the commercial sector through to 2030 – were drawn from the World Bank and USAID.[47] These are scaled to urban West Bengal using state-level data on the number of commercial establishments.[48] Electricity consumption in commercial buildings was available from the Kolkata Municipal Authority at district level. There are no data available on the consumption of other fuels in this sector. We therefore assume that the ratio of electricity use to other fuel use for commercial buildings is half that of the domestic sector, based on consultationsthat recognized lower cooking and heating needs in commercial buildings.

In the absence of data on the composition of electricity demand from different appliances in the commercial sector, we made the assumption that there is a consistent average energy saving from shifting to energy efficient appliances as is forecast for the residential sector. This means that the source of potential savings is known by type in the residential sector but not in the commercial sector.

The scope for the deployment of different low carbon options is estimated assuming that commercial buildings have the same technical potential to use renewable energy technologies per unit of floor space as the residential sector. However, commercial buildings are likely to have a more business-aware ownership, use more energy per unit area and also possibly have greater usable rooftop area then residential buildings. We therefore assumed that a greater proportion of the technical potential will be utilised for the commercial sector than the residential sector. Two scenarios were modelled: a ‘realistic’ uptake of 20% of the maximum technical potential and an ‘ambitious’ uptake of 40% of the maximum technical potential. The same approach and scenarios were adopted for behavioural change, except that the scope for implementation was scaled from the residential sector figures according to the relative amount of electricity used in the commercial sector rather than the relative amount of floor space.

To calculate the costs and carbon savings of ECBC standards, we calculated the average energy use per unit of commercial floor space by dividing total floor space of residential buildings by the total energy consumed by the commercial sector. This provided a baseline to determine energy savings with the implementation of ECBC energy efficiency targets in all new offices, hotels, hospitals, retail/wholesale and other commercial buildings. The costs of achieving ECBC standards for new buildings are estimated to be 12.5% of initial investment costs,[49] and the cost of retrofitting is estimated to be 20% of the current base cost of construction. Commercial buildings in both the business as usual and ECBC scenario are assumed to increase their energy use per unit area over time, in accordance with background rates in the baseline. We attribute this to increased appliance use and ownership in response to rising real incomes.

Industry

To build our data set on industrial output, energy use and emissions in the KMA, we use available data from West Bengal (which contains but goes beyond the boundaries of KMA) and Kolkata (which forms only a part of the KMA).

Whilst there is data on electricity use by industrial sector in the KMA[50], there are no data on other forms of energy use or emissions from industry in the KMA. However, this data do exist by industrial sector for West Bengal for each year from 2001 to 2009. We downscale this to KMA by assuming that the ratios of electricity consumption to broader fuel use for each industrial sector in KMA are the same as those for West Bengal.

To adjust for the scale of output from each industrial sector in KMA, we use figures from Kolkata in 2000/1, 2004/5 and 2007/8[51] and adjust them to reflect the size and sectoral composition of industry in the wider KMA area based on industrial output by district. We base our forecasts for industrial output and energy use to 2025 on an extrapolation of these trends. Fuel prices in the industrial sector are projected to rise 3% in real terms per annum.

The long list of potential sources of mitigation options was drawn from workshops, individual business case studies from within the KMA as well as research from the Bureau of Energy Efficiency and the Confederation of Indian Industry and relevant cases drawn from the Clean Development Mechanism.[52,53,54,55,56] The refined list was based on the Bureau of Energy Efficiency cluster reports of energy efficiency opportunities in different industrial sectors in India. We assume that the characteristics of particular sectors in the KMA are the same as for the sectors used in this report.

Transport

Data for the transport sector are obtained from the Bureau of Applied Economics and Statistics for West Bengal,[57] the West Bengal Pollution Board[58], the Ministry of Indian Railways,[59] the Energy Group of Prayas,[60] the Confederation of Indian Energy,[61] mypetrolprice.com[62], the Indian Energy Outlook[63]and the Kolkata Metropolitan Development Authority.[64]

Projected growth rates of vehicle ownership have been forecast for each type of vehicle based on real data on vehicle registration from 2001-2009. We exclude the impact of the ban on commercial vehicles over fifteen years old that came into effect in 2008-2009 on broader trends in vehicle ownership. These growth rates vary from 1.7% per annum for buses to 7.2% for motorbikes. Vehicle numbers are scaled to the KMA area by adjusting district-level data by population data. We assume that rates of use for road transport modes remain constant under business as usual conditions. Fuel efficiency for heavy duty vehicles and motor cars is projected to continue to increase in line with background trends, but low background replacement rates slow the rate of improvement in efficiencies in a business as usual scenario.

Fuel process are projected to rise 3% per annum, ia conservative estimate based on price trends over the past decade. Reducing fuel subsidies would substantially increase the economic feasibility of all measures from the perspective of end users. The model accounts for the marginal cost of purchasing new vehicles with improved efficiency, using background replacement rates assumed to be 4% for HDVs and 5% for private cars based on observed data[65] and expert consultation. The operating and fuel costs of new infrastructure, such as the BRT, are incorporated in estimates of investment needs and payback periods.

Waste

Figures on waste production, composition and collection are compiled from real data for Kolkata for 2008.[66], A decadal waste production growth rate of 13.6% per capita is used based on national level trends in India.[67] Within Kolkata, we assumed that the majority of waste is treated as landfill, except for 15% which is informally recycled[68] and 300t/day which is composted. Kolkata-specific waste composition data for 2000[69] and 2010[70] reveals an increasing share of compostables and a declining share of recyclables. All emissions related to waste are assumed to be in the year of disposal and are calculated using the international method as outlined in the Global Protocol for Community-Scale Emissions.[71]

A number of GHG mitigation measures exist for the waste sector, although their financial viability does vary and the potential for these technologies to be deployed depends on the physical characteristics of the waste and degree of pre-sorting undertaken. For each measure considered, we assess the capacity, necessary capital, operating costs and potential income generated by the measure. The data used to develop the list of measures and the assessments of their performance and scope for deployment are based on a number of different sources including academic papers, CDM reports, current waste management plans and the expert group.

When calculating the costs of some waste management measures which typically have a disposal charge, a fee of 84 INR/t is assumed based on the current costs of waste management in Kolkata (scaled to the KMA area and accounting for final disposal costs).[72] There are also opportunities to generate income from waste management options. The Clean Development Mechanism could help finance composting, landfill gas capture, incineration, gasification, refuse derived fuels (RDF) and anaerobic digestion (AD) with related revenue has been valued at USD 0.3/tCO_2e in 2013 (reflecting international prices for CDM credits) with an assumed 5% rise in prices per year. Where measures such as incineration, gasification, RDF, AD and in- vessel composting could generate electricity, a sale price of 2.25Rs/Kwh in 2013 with a 5% price escalator per annum has been used.

Appendix C: League table of the most cost-effective measures for the city.

- Cost effective
- Cost neutral
- All others including "cost ineffective" and those mutually exclusive with other measures

Rank:	Sector	Measure:	IDR/ tCO_2-e	USD/ tCO_2-e
1	Transport	Parking demand management	-80,626	-1,380
2	Industry	Basic metals & fabrication - Waste heat recovery (oil-fired melting)	-22,390	-383
3	Industry	Paper, wood, printing and products - Pressurised head box	-21,770	-372
4	Industry	Basic metals & fabrication - Wood gasifier (oil-fired melting)	-20,141	-344
5	Industry	Basic metals & fabrication - Waste heat recovery (coke-fired melting)	-16,335	-279
6	Transport	Commercial vehicle efficiency standards (introduction 2018)	-16,117	-276
7	Industry	Chemicals, rubber and plastics - Insulation of cyclone system in spray dryers	-14,634	-250
8	Industry	Basic metals & fabrication - Induction furnace for melting	-14,591	-249
9	Industry	Basic metals & fabrication - Wood gasifier (coke-fired melting)	-14,506	-248
10	Industry	Chemicals, rubber and plastics - Installation of exhaust gas heat recovery system in spray dryer	-13,909	-238
11	Industry	Non-metallic - Installation of recuperator in tunnel kiln	-11,435	-196
12	Commercial	20kWp solar PV panel with FiT	-11,353	-194
13	Industry	Non-metallic - Use of hot air of cooling zone of tunnel kiln as combustion air	-11,299	-193
14	Industry	Non-metallic - Installation of low thermal mass cars in tunnel kiln for sanitary wares	-9,634	-165
15	Industry	Paper, wood, printing and products - Energy efficiency improvements in process pumps	-9,520	-163
16	Industry	Paper, wood, printing and products - Boiler feed water pressure drop	-9,039	-155
17	Industry	Paper, wood, printing and products - Flash steam recovery	-8,974	-153
18	Industry	Paper, wood, printing and products - Boiler feed water pump efficiency improvement	-8,969	-153
19	Industry	Non-metallic - Use of energy efficient motor for polishing line	-8,149	-139
20	Industry	Paper, wood, printing and products - Installation of screw press	-8,061	-138
21	Industry	Non-metallic - Installation of natural gas turbine for electricity generation and use of exhaust flue gas of turbine in spray dryer	-7,995	-137
22	Industry	Basic metals & fabrication - Energy efficient pit furnace (coke-fired melting)	-7,705	-132
23	Industry	Chemicals, rubber and plastics - Matching the centre of motor axis with ball mill axis	-7,341	-126

Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Rank:	Sector	Measure:	IDR/ tCO_2-e	USD/ tCO_2-e
24	Industry	Paper, wood, printing and products - Installation of high consistency pulper	-6,833	-117
25	Industry	Chemicals, rubber and plastics - Replacement of conventional gear system with planetary gear system in reaction vessels	-6,778	-116
26	Industry	Textiles - Variable frequency drives	-6,552	-112
27	Industry	Textiles - Tri-generation micro turbine	-6,442	-110
28	Industry	Textiles - Energy efficient pumps	-6,361	-109
29	Industry	Chemicals, rubber and plastics - Energy efficient motors	-6,354	-109
30	Industry	Chemicals, rubber and plastics - Replacement of conventional V belts with flat belts in various drives	-6,281	-107
31	Industry	Non-metallic - Use of hot air of final cooling of tunnel kiln	-6,009	-103
32	Industry	Non-metallic - Installation of briquette fired hot air generator	-5,782	-99
33	Industry	Basic metals & fabrication - Thermo couples for annealing furnace	-5,724	-98
34	Industry	Basic metals & fabrication - Modified wood fired annealing furnace	-5,636	-96
35	Domestic	Solar water heating with FiT	-5,521	-94
36	Industry	Textiles - Natural gas generator with co-generation	-5,041	-86
37	Domestic	4kWp solar PV panel with FiT	-4,963	-85
38	Commercial	Banning incandescent light bulbs	-4,674	-80
39	Industry	Chemicals, rubber and plastics - Replacement of conventional horizontal agitator system with vertical agitator system	-4,666	-80
40	Industry	Textiles - Steam based co-generation system	-4,464	-76
41	Industry	Non-metallic - Installation of natural gas engine for electricity generation and use of exhaust flue gas of engine in spray dryer	-4,346	-74
42	Electricity	Coal retrofit (6045MW)	-4,155	-71
43	Industry	Basic metals & fabrication - Wood gasifier for annealing	-3,974	-68
44	Industry	Chemicals, rubber and plastics - Improvements in hot air distribution system	-3,811	-65
45	Industry	Chemicals, rubber and plastics - Improving insulation of hot air generator	-3,764	-64
46	Industry	Chemicals, rubber and plastics - Energy efficient hot air generator system	-3,414	-58
47	Industry	Chemicals, rubber and plastics - Energy efficient wood-fired boiler	-3,383	-58
48	Industry	Chemicals, rubber and plastics - Energy efficient tray dryer system	-3,354	-57
49	Domestic	Banning incandescent light bulbs	-3,308	-57
50	Transport	CNG bus replacement (introduction 2020)	-3,199	-55
51	Industry	Non-metallic - Improvement in kiln, spray dryer & other hot surfaces insulation	-3,076	-53
52	Industry	Chemicals, rubber and plastics - Replacement of manual filter press with mechanical filter press	-2,911	-50
53	Industry	Chemicals, rubber and plastics - Replacement of conventional filter press (recess plates) with membrane filters press	-2,892	-49

Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Rank:	Sector	Measure:	IDR/ tCO_2-e	USD/ tCO_2-e
54	Industry	Chemicals, rubber and plastics - Replacement of conventional wood fired tray dryer system with solar tray dryer system	-2,682	-46
55	Commercial	Electronics - energy management	-2,643	-45
56	Industry	Non-metallic - Energy efficiency improvements in motors of agitation section	-2,540	-43
57	Domestic	Raising thermostat 1˚C	-2,488	-43
58	Commercial	Raising thermostat 1˚C	-2,475	-42
59	Domestic	Entertainment appliances - standby	-2,461	-42
60	Industry	Textiles - Heat recovery system	-2,440	-42
61	Domestic	Air conditioner - EE Standard 1	-2,333	-40
62	Industry	Textiles - Online flue gas monitoring system	-2,266	-39
63	Domestic	Air conditioner - EE Standard 2	-2,259	-39
64	Domestic	4kWp solar PV panel	-2,218	-38
65	Commercial	Elevators and escalators - EE Standard 1	-2,167	-37
66	Commercial	Elevators and escalators - EE Standard 2	-2,167	-37
67	Domestic	Turning off lights	-2,113	-36
68	Domestic	Green Building Standard 1 (40% of new households from 2015)	-2,036	-35
69	Domestic	Green Building Standard 2 (20% of new households from 2015)	-2,036	-35
70	Domestic	Water heater - EE Standard 2	-1,855	-32
71	Domestic	Water heater - EE Standard 1	-1,845	-32
72	Domestic	Setting LED target of 25%	-1,841	-31
73	Domestic	Solar water heating	-1,794	-31
74	Domestic	Entertainment appliances - EE Standard 1	-1,731	-30
75	Domestic	Entertainment appliances - EE Standard 2	-1,572	-27
76	Industry	Textiles - Energy efficient boilers	-1,478	-25
77	Industry	Non-metallic - Preheating of input slurry of spray dryer through solar energy	-1,474	-25
78	Industry	Non-metallic - Implementation of ON - OFF system (10 minutes ON and 5 minutes OFF) for agitation motors	-1,342	-23
79	Commercial	Air conditioner - EE Standard 2	-1,307	-22
80	Commercial	Air conditioner - EE Standard 1	-1,260	-22
81	Industry	Chemicals, rubber and plastics - Energy efficient gas fired hot air generator system	-1,017	-17
82	Industry	Paper, wood, printing and products - Boiler fans efficiency improvements	-801	-14
83	Industry	Paper, wood, printing and products - Boiler efficiency improvement	-796	-14
84	Industry	Paper, wood, printing and products - Digester blow heat recovery	-742	-13
85	Domestic	Retrofitting mineral wool insulation	-556	-10
86	Industry	Paper, wood, printing and products - Steam consumption reduction by efficient condensate evacuation	-549	-9
87	Industry	Non-metallic - Preheating of combustion air by smoke air through recuperator in ceramic tiles	-520	-9

Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Rank:	Sector	Measure:	IDR/ tCO_2-e	USD/ tCO_2-e
88	Domestic	Retrofitting fibreglass urethane insulation	-452	-8
89	Domestic	Refrigerator - EE Standard 2	-286	-5
90	Industry	Paper, wood, printing and products - Installation of pocket ventilation system	-275	-5
91	Waste	Improved recycling	-260	-4
92	Transport	Car vehicle efficiency standards (introduction 2014)	-250	-4
93	Waste	Gasification	-135	-2
94	Industry	Non-metallic - Installation of variable frequency drive (VFD) in motors of agitation system	-102	-2
95	Commercial	Setting LED target of 25%	-3	0
96	Commercial	Turning off lights	-3	0
97	Domestic	Solar lamps for outdoor lighting	-2	0
98	Commercial	Green Buildings Standard 1	-2	0
99	Commercial	Green Buildings Standard 2	-2	0
100	Industry	Textiles - Energy efficiency stenters	0	0
101	Waste	Refuse-derived fuel	14	0
102	Commercial	20kWp solar PV panel - Scenario 1	24	0
103	Industry	Non-metallic - Installation of variable frequency drive (VFD) in ball mill and blunger	52	1
104	Waste	Landfill gas flaring	143	2
105	Industry	Textiles - Pressure powered pumping packing unit	223	4
106	Domestic	Refrigerator - EE Standard 1	354	6
107	Waste	Windrow composting	519	9
108	Domestic	Washing machine - EE Standard 1	602	10
109	Waste	Anaerobic digestion	678	12
110	Electricity	Solar PV (900 MW)	1,024	18
111	Electricity	Solar PV (450 MW)	1,408	24
112	Electricity	Wind (450 MW)	1,419	24
113	Domestic	Fuel switching - coal to LPG	1,685	29
114	Waste	In-vessel composting	1,696	29
115	Domestic	Washing machine - EE Standard 2	1,710	29
116	Waste	Incineration	2,739	47
117	Waste	Sanitary semi-aerobic landfills	4,785	82
118	Domestic	Fuel switching - cow-dung cake to LPG	5,902	101
119	Transport	Tram network recapitalisation and roadway designation	11,172	191
120	Transport	BRT (42.5km)	68,230	1,167
121	Transport	Cycling infrastructure	90,675	1,552

Appendix D:
League table of the most carbon-effective measures for the city.

Cost effective

Cost neutral

All others including “cost ineffective” and those mutually exclusive with other measures

Rank:	Sector	Measure:	$ktCO_2$-e
1	Electricity	Coal retrofit (6045MW)	61,435
2	Electricity	Solar PV (900 MW)	14,083
3	Electricity	Wind (450 MW)	8,450
4	Electricity	Solar PV (450 MW)	7,041
5	Commercial	Green Buildings Standard 2 (100% of new buildings)	6,768
6	Domestic	Air conditioner - EE Standard 2	6,003
7	Domestic	Retrofitting fibreglass urethane insulation (20% of existing households by 2025)	4,989
8	Domestic	Air conditioner - EE Standard 1	4,560
9	Commercial	Air conditioner - EE Standard 2	3,688
10	Domestic	Entertainment appliances - EE Standard 2	3,529
11	Domestic	Turning off lights	3,519
12	Commercial	Green Buildings Standard 1 (100% of new buildings)	3,384
13	Commercial	Green Buildings Standard 2 (50% of new buildings)	3,384
14	Domestic	Entertainment appliances - EE Standard 1	2,937
15	Domestic	Retrofitting mineral wool insulation (20% of existing households by 2025)	2,661
16	Industry	Textiles - Heat recovery system	2,507
17	Domestic	Retrofitting fibreglass urethane insulation (10% of existing households by 2025)	2,494
18	Industry	Non-metallic - Installation of natural gas turbine for electricity generation and use of exhaust flue gas of turbine in spray dryer	2,318
19	Domestic	Water heater - EE Standard 2	2,205
20	Industry	Non-metallic - Installation of natural gas engine for electricity generation and use of exhaust flue gas of engine in spray dryer	2,200
21	Industry	Textiles - Energy efficient boilers	2,146
22	Industry	Non-metallic - Preheating of combustion air by smoke air through recuperator in ceramic tiles	2,085
23	Transport	Commercial vehicle efficiency standards (introduction 2018)	1,933
24	Commercial	Air conditioner - EE Standard 1	1,844
25	Commercial	Electronics - energy management	1,830
26	Domestic	Entertainment appliances - standby	1,710
27	Commercial	Green Buildings Standard 1 (50% of new buildings)	1,692
28	Industry	Textiles - Steam-based co-generation system	1,666
29	Waste	Gasification	1,618
30	Industry	Textiles - Tri-generation micro turbine	1,489
31	Domestic	Banning incandescent light bulbs	1,426
32	Transport	CNG bus replacement (introduction 2020)	1,417
33	Industry	Textiles - Online flue gas monitoring system	1,399

Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Rank:	Sector	Measure:	$ktCO_2$-e
34	Domestic	Retrofitting mineral wool insulation (10% of existing households by 2025)	1,330
35	Industry	Textiles - Energy efficient pumps	1,210
36	Domestic	Raising thermostat 1˚C	1,174
37	Waste	Incineration	1,165
38	Transport	Parking demand management	1,138
39	Commercial	Turning off lights	999
40	Domestic	Water heater - EE Standard 1	938
41	Industry	Paper, wood, printing and products - Boiler efficiency improvement	889
42	Domestic	4kWp solar PV panel with FiT (10MW by 2025)	887
43	Domestic	4kWp solar PV panel (10MW by 2025)	887
44	Waste	Refuse-derived fuel	860
45	Domestic	Solar water heating with FiT (10% of households by 2025)	852
46	Domestic	Solar water heating (10% of households by 2025)	852
47	Waste	Anaerobic digestion	843
48	Industry	Non-metallic - Preheating of input slurry of spray dryer through solar energy	835
49	Industry	Textiles - Natural gas generator with co-generation	786
50	Industry	Non-metallic - Installation of briquette fired hot air generator	688
51	Industry	Non-metallic - Improvement in kiln, spray dryer & other hot surfaces insulation	646
52	Domestic	Refrigerator - EE Standard 2	617
53	Transport	BRT (42.5km)	615
54	Industry	Non-metallic - Installation of variable frequency drive (VFD) in ball mill and blunger	591
55	Industry	Chemicals, rubber and plastics - Energy efficient wood-fired boiler	571
56	Commercial	Raising thermostat 1˚C	548
57	Industry	Chemicals, rubber and plastics - Energy efficient tray dryer system	533
58	Industry	Chemicals, rubber and plastics - Replacement of conventional wood fired hot air generator system with energy efficient gas fired hot air generator system	479
59	Commercial	Banning incandescent light bulbs	477
60	Commercial	Elevators and escalators - EE Standard 2	469
61	Waste	Windrow composting	460
62	Domestic	4kWp solar PV panel (5MW by 2025)	444
63	Waste	In-vessel composting	442
64	Industry	Chemicals, rubber and plastics - Replacement of conventional filter press (recess plates) with membrane filters press	429
65	Domestic	Solar water heating (5% of households by 2025)	426
66	Domestic	Setting LED target of 25%	423
67	Transport	Car vehicle efficiency standards (introduction 2014)	370
68	Industry	Chemicals, rubber and plastics - Replacement of conventional wood fired tray dryer system with solar tray dryer system	343
69	Industry	Paper, wood, printing and products - Digester blow heat recovery	324
70	Industry	Chemicals, rubber and plastics - Energy efficient hot air generator systems	311

Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Rank:	Sector	Measure:	$ktCO_2$-e
71	Industry	Chemicals, rubber and plastics - Installation of exhaust gas heat recovery system in spray dryer	288
72	Transport	Tram network recapitalisation and roadway designation	287
73	Industry	Paper, wood, printing and products - Boiler fans efficiency improvement	272
74	Industry	Chemicals, rubber and plastics - Replacement of manual filter press with mechanical filter press	267
75	Industry	Paper, wood, printing and products - Steam consumption reduction by efficient condensate evacuation	242
76	Commercial	Elevators and escalators - EE Standard 1	235
77	Waste	Improved recycling	226
78	Industry	Textiles - Pressure powered pumping packing unit	200
79	Industry	Non-metallic - Implementation of ON - OFF system (10 minutes ON and 5 minutes OFF) for agitation motors	192
80	Domestic	Fuel switching - coal to LPG	190
81	Commercial	Setting LED target of 25%	178
82	Domestic	Washing machine - EE Standard 2	174
83	Waste	Sanitary semi-aerobic landfills	153
84	Waste	Landfill gas flaring	143
85	Industry	Chemicals, rubber and plastics - Improvements in hot air distribution system	139
86	Domestic	Washing machine - EE Standard 1	136
87	Transport	Cycling infrastructure	131
88	Domestic	Refrigerator - EE Standard 1	123
89	Domestic	Green Building Standard 2 (40% of new households from 2015)	119
90	Industry	Paper, wood, printing and products - Installation of pocket ventilation system	119
91	Industry	Non-metallic - Energy efficient motors in agitation section	117
92	Industry	Non-metallic - Installation of variable frequency drive (VFD) in motors of agitation system	98
93	Industry	Chemicals, rubber and plastics - Replacement of conventional horizontal agitator system with vertical agitator system	97
94	Industry	Chemicals, rubber and plastics - Improving insulation of hot air generator	87
95	Industry	Textiles - Energy efficiency stenters	86
96	Industry	Non-metallic - Use of energy efficient motor for polishing line	81
97	Industry	Basic metals & fabrication - Wood gasifier (coke-fired melting)	72
98	Industry	Textiles - Variable frequency drives	64
99	Industry	Non-metallic - Use of hot air of final cooling of tunnel kiln for preheating the input material	63
100	Domestic	Green Building Standard 1 (40% of new households from 2015)	60
101	Industry	Basic metals & fabrication - Thermo couples for annealing furnace	57
102	Industry	Basic metals & fabrication - Wood gasifier for annealing	57
103	Industry	Chemicals, rubber and plastics - Replacement of conventional motors with energy efficient motors	56
104	Industry	Basic metals & fabrication - Induction furnace for melting	54

Cost effective

Cost neutral

All others including "cost ineffective" and those mutually exclusive with other measures

Rank:	Sector	Measure:	$ktCO_2$-e
105	Industry	Basic metals & fabrication - Wood gasifier (oil-fired melting)	51
106	Domestic	Solar lamps for outdoor lighting (100% of outdoor lamps sold)	45
107	Industry	Non-metallic - Installation of low thermal mass cars in tunnel kiln for sanitary wares	43
108	Industry	Basic metals & fabrication - Modified wood-fired annealing furnace	33
109	Domestic	Green Building Standard 2 (20% of new households from 2015)	30
110	Domestic	Green Building Standard 1 (20% of new households from 2015)	30
111	Industry	Paper, wood, printing and products - Energy efficiency improvement in process pumps	27
112	Industry	Chemicals, rubber and plastics - Replacement of conventional gear system with planetary gear system in reaction vessels	26
113	Industry	Chemicals, rubber and plastics - Matching the centre of motor axis with ball mill axis	25
114	Domestic	Solar lamps for outdoor lighting (50% of outdoor lamps sold)	22
115	Industry	Non-metallic - Use of hot air of cooling zone of tunnel kiln as combustion air	19
116	Industry	Non-metallic - Installation of recuperator in tunnel kiln thereby preheating combustion air through smoke air	18
117	Industry	Chemicals, rubber and plastics - Replacement of conventional V belts with flat belts in various drives	17
118	Industry	Chemicals, rubber and plastics - Insulation of cyclone system in spray dryers	16
119	Industry	Paper, wood, printing and products - Boiler feed water pump efficiency improvements	16
120	Commercial	20kWp solar PV panel (80% of buildings)	15
121	Commercial	20kWp solar PV panel with FiT (80% of buildings)	15
122	Industry	Paper, wood, printing and products - Installation of screw press	13
123	Industry	Basic metals & fabrication - Energy efficient pit furnace (coke-fired melting)	12
124	Industry	Paper, wood, printing and products - Flash steam recovery	8
125	Commercial	20kWp solar PV panel (40% of buildings)	8
126	Commercial	20kWp solar PV panel with FiT (40% of buildings)	8
127	Industry	Paper, wood, printing and products - Pressurised head box	7
128	Industry	Basic metals & fabrication - Waste heat recovery (coke-fired melting)	6
129	Industry	Basic metals & fabrication - Waste heat recovery (oil-fired melting)	4
130	Industry	Paper, wood, printing and products - Boiler feed water pressure drop reduction	4
131	Industry	Paper, wood, printing and products - Installation of high consistency pulper	2
132	Domestic	Fuel switching - cow-dung cake to LPG	0

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About CLCF

The Centre for Low Carbon Futures is a collaborative membership organisation that focuses on sustainability for competitive advantage. Formed by the University of Birmingham, University of Hull, University of Leeds, University of Sheffield and University of York, we work across the EU, Asia and Latin America. The Centre brings together engineers, natural scientists and social scientists to deliver high impact research. Our 2013/14 themes are Energy Systems, Green Growth and Smart Infrastructure.

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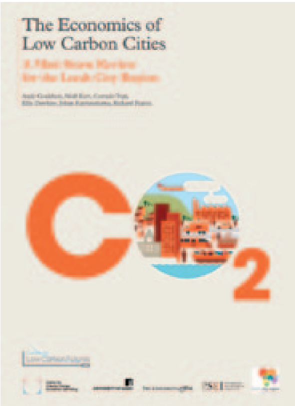
Climate Smart Cities

Kolkata, India

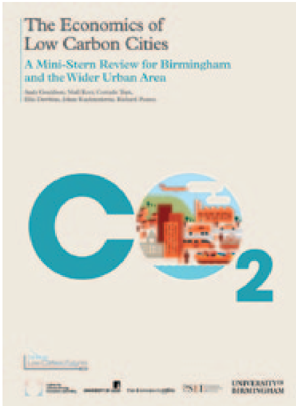
Lima-Callao, Peru

Palembang, Indonesia

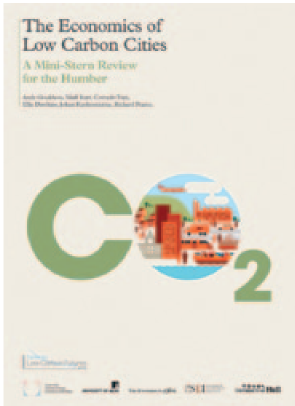
Johor Bahru, Malaysia



Leeds City Region



Birmingham and the Wider Urban Area



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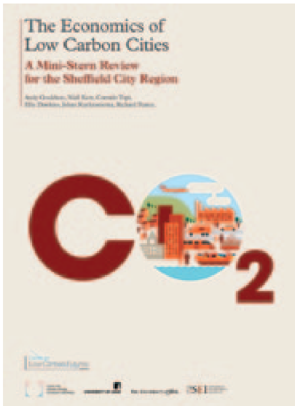

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