# The Economics of Low Carbon Cities:

## Recife, Brazil


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# The Economics of Low Carbon Cities

## Recife, Brazil

## Today

8.7% of city-scale GDP leaves the local economy every year through payment of the energy bill. In 2030, this could increase to 12.1% of city-scale GDP.

8.7% of GDP leaks out of the economy


## Tomorrow

Investing 0.9% of GDP p.a.

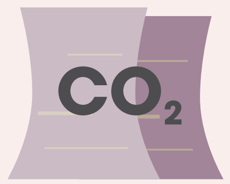
0.9% of GDP could be profitably invested, every year for ten years, to exploit commercially attractive energy efficiency and low carbon opportunities.

Leads to...

- **Energy**
  reductions in the energy bill equalling 3.5% of GDP
- **Financial viability**
  5.6 years for measures 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

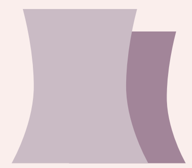
**Potential to reduce $CO_2$ emissions**

2000



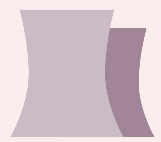

2025

24.3% $CO_2$ reduction



Through cost-effective investments in the city.

31.0% $CO_2$ reduction



Through cost-neutral investments in the city.

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# Foreword: Foreign and Commonwealth Office

I am delighted to highlight the excellent collaboration between the UK and Brazil on a challenge facing many cities; sustainability.

The University of Leeds and their Brazilian partner, ICLEI Brazil, have worked together on possible solutions. The report they have produced focusses on the link between energy and development in the fast growing city of Recife in the North East of Brazil. It reviews the cost and effectiveness of a wide range of efficient, renewable and low carbon options for urban development.

Recife's metropolitan region is formed by 14 municipalities in which 42% of the state's population is concentrated in 2.81% of the state's territory, totalling an average of 7,000 people per square kilometre – almost the triple of London's density. Rapid growth and high density has led to severe problems in water supply and recurring flooding.

The need for urban planning and innovative technology to tackle these issues in order to mitigate the effects of climate change, and the impact of human development is the starting point for this report. Using their experience, the University of Leeds suggests smart city solutions by which the established Climate Change and Sustainability Committee of the city of Recife can implement a low emission development strategy.

I hope the report can help Recife to realise its ambition of being a low-carbon city with high economic growth and which offers its inhabitants a high quality of life. Enjoy reading it.

**Alexander Wykeham Ellis**
**Her Majesty´s Ambassador to Brazil**



# Foreword: ICLEI

Latin America is one of the regions with the highest rates of urbanisation in the entire planet: around 75% to 85% of the population lives in cities in the majority of countries. The lack of planning and uncoordinated growth in many urban areas results in a range of environmental and social-economic impacts. In the next 40 years, it will be necessary to build the same urban capacity as over the last 4,000 years. Considering this growing demand and the deterioration of natural resources, the cities and urban systems need to be redesigned and re-planned in order to produce more of the resources that they consume, such as food and energy, and to be more compact. The relationships between cities and natural resources is driving a current discussion of urban planning to realise a green urban economy.

Facing this scenario, it is crucial that cities see these challenges not as problems, but as opportunities to become more efficient, productive and equal spaces, protecting their valuable natural resources and providing better living conditions for local inhabitants. The development of long-term strategies and integrated policy implementation could be a pathway to transform the current scenarios.

Local governments, as the closest governance level to each citizen, have the role and responsibility to build more sustainable cities. For this task, they can look for ICLEI´s support. ICLEI-Local Governments for Sustainability is the main global association of cities and local governments focusing on sustainable development. It represents a powerful movement of 12 megacities, 100 super-cities, 450 big cities and urban regions, as well as 450 small and medium-sized cities in 83 countries. ICLEI has the mission to build and serve a worldwide movement of local governments to achieve actual improvements in global sustainability, with special attention to environmental conditions, through cumulative actions. ICLEI promotes local actions for global sustainability, and supports cities to become more resilient, efficient in the use of resources, biodiverse and low-carbon, and to develop a green inclusive urban economy supporting a happy and healthy community.

In this sense, ICLEI believes that Recife is on the right track to make a real transition from a traditional economy based on fossil fuel and grey infrastructure to an inclusive low carbon society, bringing elements that will enable the city to become smarter and more sustainable.

As a result of this report written by the University of Leeds, the City of Recife has seen some alternatives that could be included in its Low Emission Development Action Plan, hence building its long-term planned strategy.

**Jussara Carvalho**
**Executive Director**
**ICLEI**

# Executive Summary

## Introduction

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 major obstacles that may prevent cities from acting on such a far-reaching 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 Recife and to use this to examine whether there is an economic case that can be used to secure large-scale, low carbon investments 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 housing, commercial buildings, transport and waste sectors within the city.

## Our Approach

We start the analysis by collecting data on levels and composition of energy use in Recife. We do this for a range of different sectors including the electricity sector on the supply side and the housing, commercial, 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. The primary data was supplied by the City of Recife.

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 that continue these trends through to 2030. These baselines allow us to predict future levels and forms of energy supply and demand, as well as future energy bills and carbon emissions.

Based on extensive literature reviews and stakeholder consultations, we then compile lists of the low carbon measures that could potentially be applied in the domestic, commercial and public buildings, transport and waste sectors in the city. The industry sector was excluded at this stage because the city's Master Plan constrains industrial activities within Recife. We assess the performance of each measure by conducting a realistic assessment of its costs and likely lifetime savings, and we consider the scope for deploying each one in Recife in the period to 2030. These appraisals were subjected to a participatory review in expert workshops to ensure that they are as realistic as possible and to consider the key factors that shape the potential for their deployment.

We draw together the results from our assessment and the expert review 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, energy 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.



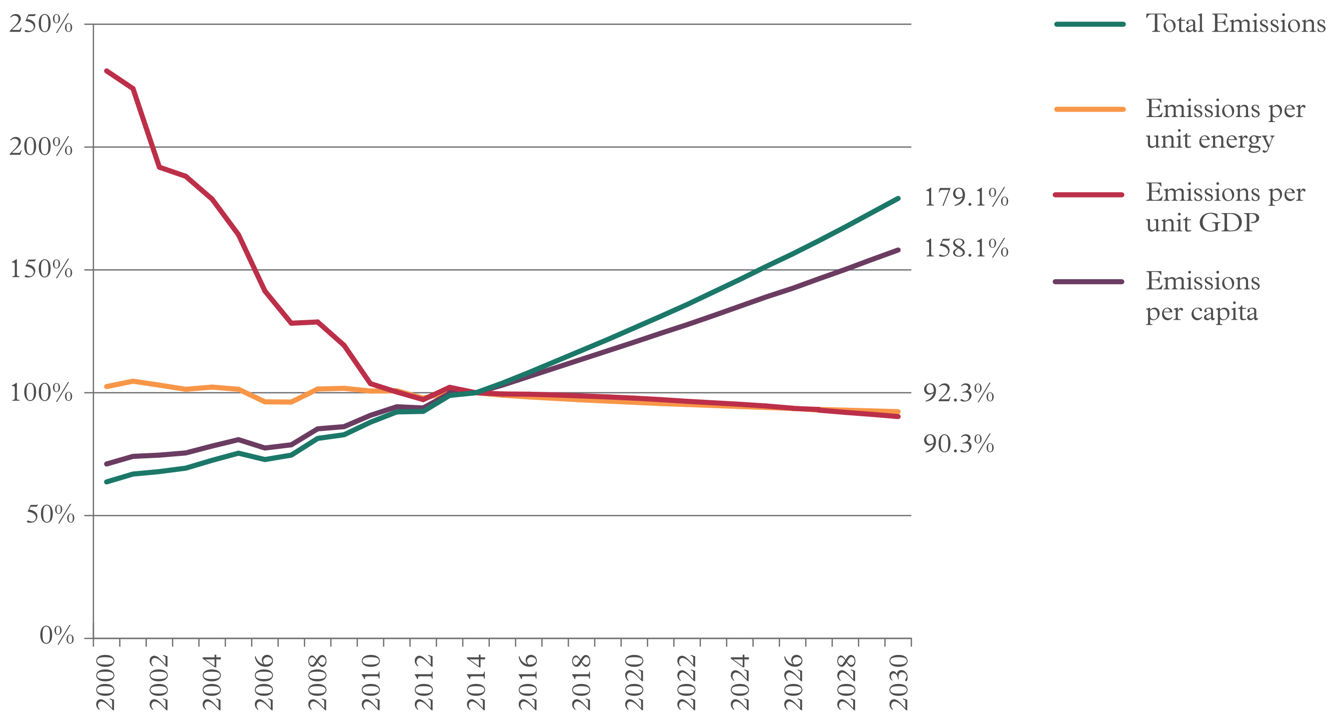
The cost-benefit analysis of each measure was complemented by a multi-criteria appraisal. We convened a series of stakeholder workshops where participants were invited to assess each measure according to five broad criteria: political acceptability, public acceptability, capacity for implementation, positive impacts on human development and positive impacts on the environment. Each of these criteria in turn were apportioned a percentage weighting in order to assess their relative importance. The total score for each option or cluster of options was then calculated using the weighted average score, allowing us to identify those measures with broad political, social and environmental appeal.

## The Economic Case for Low Carbon Investment

We estimate that Recife's GDP was BRL 35.60 billion (USD 16.55 billion) in 2014, and if recent trends continue we forecast that GDP will grow to BRL 70.54 billion (USD 32.82 billion) by 2030. We also find that the total energy bill for Recife in 2014 was BRL 3.40 billion (USD 1.45 billion), meaning that 8.7% of all income earned in Recife is currently spent on energy. Energy bills are projected to increase to 12.1% of city-scale GDP by 2030.

We predict that a continuation of business as usual trends in the period to 2030 would see total energy use in Recife rising by 94.1% from 2014 levels to 2030 and we forecast that the total energy bill for the cities will increase by 174.2% from 2014 levels to BRL 9.32 billion (USD 3.97 billion) in 2030. We also predict that, in a business as usual scenario, total carbon emissions from Recife are forecast to increase by 79.1% from 2014 levels by 2030.

**Figure 1: Indexed carbon emissions – total, per unit of energy, per unit of GDP and per capita.**



After examining the potential costs and benefits of the wide range of energy efficiency, renewable energy and other low carbon measures that could be deployed across different sectors in the city, we find that – compared to business as usual trends – Recife could reduce their carbon emissions by 2030 by:

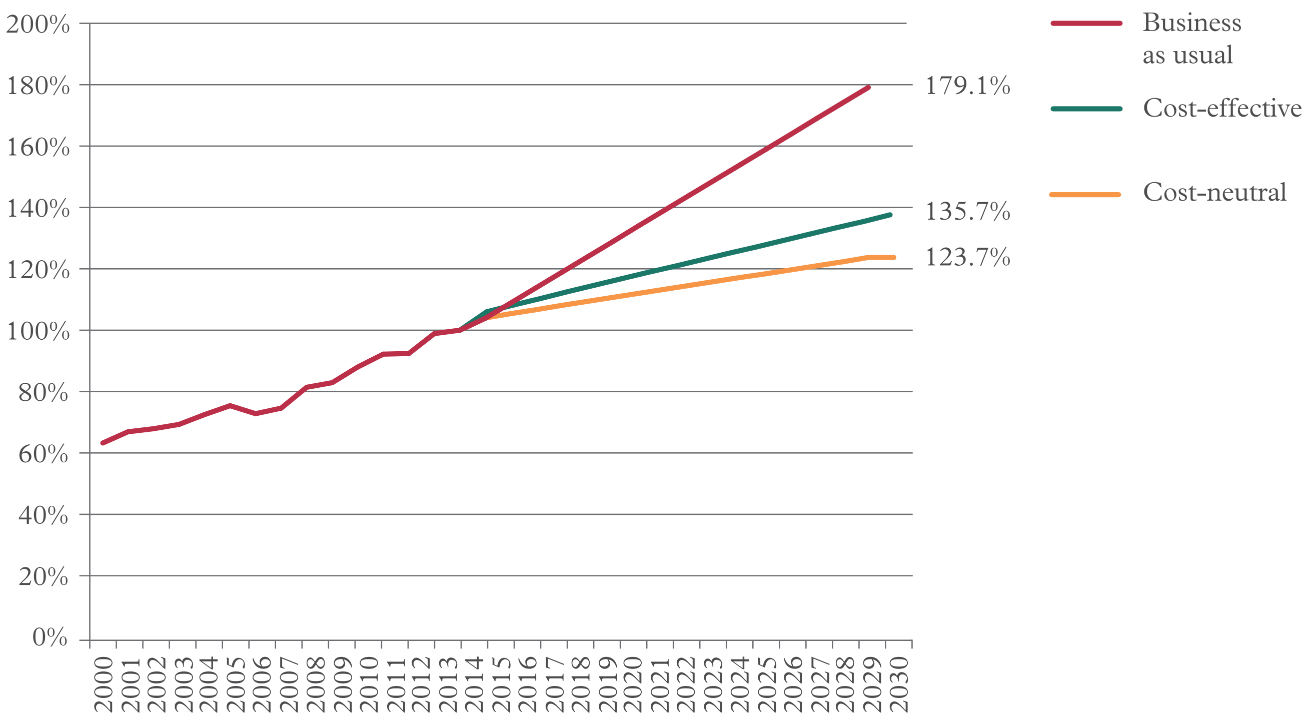
— 24.3% through cost-effective investments in the city that would more than pay for themselves on commercial terms over their lifetime. This would require an investment of BRL 7.79 billion (USD 3.32 billion), generating annual savings of BRL 1.37 billion (USD 585.25 million), paying back the investment in 5.7 years and generating annual savings for the lifetime of the measures.

— 31.0% with cost-neutral measures that could be paid for by reinvesting the income generated from cost-effective measures. This would require an investment of BRL 14.91 billion (USD 6.35 billion), generating annual cost savings of BRL 1.35 billion (USD 575.01 million), paying back the investment in 11.0 years and generating annual savings for the lifetime of the measures.

We find that the transport sector contains 58.1% of the total potential for cost-effective low carbon investments, with the remaining potential being distributed among the domestic sector (6.9%), the commercial sector (12.5%), and the waste sector (22.5%).

While the impacts of the cost-effective investments will reduce overall emissions relative to business as usual trends, they do not stop overall emissions from rising in absolute terms. With exploitation of all cost-effective options, by 2030 emissions would be 35.7% above 2014 levels. These measures will also save BRL 1.37 billion (USD 585.24 million) in energy expenditure each year, thereby reducing the energy bill in 2030 from a projected 12.1% of GDP to 8.6%. With the exploitation of all cost-neutral measures, the city's emissions rise by only 23.7% above 2014 levels instead of 79.1%.

**Figure 2: Emissions from Recife under three different scenarios between 2000 and 2030.**






However, investment in cost-effective and cost-neutral options can buy cities much needed time to lock in permanent reductions in emissions. If all cost-effective options are implemented, the Time to Reach BAU Emission Levels (TREBLE) relative to 2030 in Recife will be 22 years. If all cost-neutral measures are implemented, emissions will only reach their 2030 business as usual level in 43 years. In other words, economically neutral levels of investment in climate mitigation can keep emissions in Recife below business as usual trends for decades to come, giving policymakers time to build the political momentum and the technical, financial and institutional capabilities necessary for more ambitious changes to urban form and function.

## Conclusions and Recommendations

This research reveals that there are many economically attractive opportunities to increase energy efficiency and stimulate renewable energy investment, which would in turn improve the economic competitiveness, energy security and carbon intensity of Recife. The scale of the opportunities demonstrates that accounting for climate change in urban planning can be attractive in commercial terms, above and beyond the immense benefits of reducing the future impacts of climate change. We hope that Recife can use these findings to inform the development of its Climate Action Plan.

The presence of such opportunities does not mean that they will necessarily be exploited. By providing evidence on the scale and 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 Recife to secure the investments and develop the delivery models needed for ambitious climate action. Some of the energy efficiency and low carbon opportunities could be commercially attractive whilst others may only be viable with public investment and/or climate finance. Many of the opportunities would benefit from the support of enabling policies from government.

The University of Leeds, ICLEI and Recife City Council stress that economic considerations should not shape the transition to a low carbon development model in urban Brazil. We recognise that decision-makers should also consider the issues relating to the equity, inclusivity and broader sustainability of each measure, introduced in our multi-criteria appraisal. However, we understand that the presence of a compelling economic case is often necessary for decision-makers to consider the broader case for action. We therefore hope that this evidence base on the opportunities for low carbon investment in Recife helps to mobilise political will for and public interest in ambitious climate action in Recife.

# Chapter 1.
# Introduction, Context, Aims and Objectives

## Cities and Climate Change

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. 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.

Energy will play a pivotal role in the future development of cities. Currently, activities in cities consume 67-76% of all energy and are responsible for 71-76% of all carbon emissions (UNEP, 2012). Some estimates suggest that 10-18% of all income that is earned in cities is spent on energy (Gouldson *et al.*, 2012; Gouldson *et al.*, 2014). 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 facilitate development. The challenge is achieving sustainable and affordable energy provision – how can cities transition 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 mean 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 reduce the energy intensity of social and economic activities. 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 bills, increase energy access, improve air quality, ease congestion, create jobs and mitigate the impacts of climate change.

Focusing on Recife, 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 efficiency, renewable energy and other low carbon options that could be applied in different sectors in Recife. 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 to a more energy efficient, lower carbon development path.



## The Brazilian Context

By land, Brazil is the largest country in Latin America, and its population of nearly 200 million people makes it the fifth most populous country in the world (World Bank, 2014). During the last ten years, Brazil's economy has grown on average by 3.3% per year, so that it is now the seventh largest economy in the world (IPEA, 2014). The services sector is the most significant, accounting for 69% of total Gross Domestic Product (GDP). The largest segments within services are government, education and health. Industry represents 26% of GDP, with manufacturing, construction and mining having the largest shares in this sector. The remaining 5% of GDP is accounted for by the agricultural sector (IBGE, 2014). Due to strong social investments such as the Family Grant scheme, the average income has increased 3.1% per year (EY, 2011), leading to a decrease in the poverty level in Brazil from 21% in 2003 to 11% in 2009 (World Bank, 2014).

Brazil's rapid economic growth has been accompanied by dramatically increasing energy demand. It is projected that the energy consumption will increase 4.5% per year until 2021 (EPE, 2012), outstripping most projections of Brazil's economic growth. Brazil is the eighth largest energy consumer and the tenth largest energy producer in the world. The energy supply comes primarily from oil and other liquid fuels (47%), hydroelectricity (35%) and natural gas (8%) (EIA, 2014). The sector with greatest demand for energy in Brazil is industry, followed by the residential and commercial sectors.

Economic development, population growth and rising demand for food and energy have created environmental challenges as well as social gains. Without considering land use change and forestry, Brazil was ranked as the sixth largest GHG emitter in 2010, producing 1,049 MtCO2-e (TSP, 2010). This underscores the importance of tackling emissions from industry, transport, households, waste and other sectors that are predominately concentrated in urban centres. Table 1 below shows the source of Brazil's emissions by sector.

Brazil is classified as the most mega-diverse country in the world. The Amazon, which covers 49% of the Brazilian territory, is highly vulnerable to climate change and other impacts, as are coastal regions such Rio de Janeiro and Recife, and the Northeast with its dry climate and socio-economic disadvantages (UNFCCC, 2007). In Brazil, many extreme weather events have taken place during the last decade including frequent floods in the South, lower water levels in the Amazon basin, heat waves in major urban centres, intense drought in Northeast and a precipitation increase in South and Southeast (MCTI *et al.*, 2013).

**Table 1. Emissions by sector in Brazil (MCTI et al., 2013).**

| Sector | 1990 | 1995 | 2000 | 2005 | 2010 | Variation | |
|---|---|---|---|---|---|---|---|
| | | | Gg CO2-e | | | 1995-2005 | 2005-2005 |
| Energy | 191,543 | 232,430 | 301,096 | 328,808 | 399,302 | 41.5% | 21.4% |
| Industrial processes | 52,536 | 63,065 | 71,673 | 77,943 | 82,048 | 23.6% | 5.3% |
| Agriculture | 303,772 | 335,775 | 347,878 | 415.713 | 437,226 | 23.8% | 5.2% |
| Forestry | 815,965 | 1,950,084 | 1,324,371 | 1,167,917 | 279,163 | -40.1% | -76.1% |
| Residential | 28,939 | 33,808 | 38,550 | 41,880 | 48,737 | 23.9% | 16.4% |
| TOTAL | 1,392,756 | 2,615,162 | 2,083,570 | 2,032,260 | 1,246,477 | -22.3% | -38.7% |

Brazil's first notable commitment against climate change was in 1992, when the country hosted the United Nations Conference on Environment and Development (more commonly known as Rio Earth Summit). In 2002, Brazil signed the Kyoto Protocol and in 2008, the government launched the National Plan on Climate Change (PNMC). This plan sets the objectives of reducing deforestation rates in the Amazon by 80% by 2020, increasing the consumption of ethanol within Brazil by 11% by 2019, and increasing the amount of urban solid waste recycled by 20% by 2015. In 2009, Brazil passed the National Law for Climate Change which set a voluntary target of reducing greenhouse gases by between 36.1% and 38.9% by 2020, relative to business as usual levels (Ministério do Meoi Ambiente, 2014).

### Recife

Recife is the ninth largest city in Brazil, with a population of 1.5 million people (Bitoun *et al.*, 2010). The metropolitan region encompasses 3.7 million people, representing the fifth largest metropolitan area in Brazil. 65.1% of the GDP of Pernambuco state is concentrated in this metropolitan area, and Recife is considered the most important industrial centre of the Northeast region, producing goods and services such as sugar cane, ships, oil platforms, and electronics.

Metropolitan Recife is home to 42% of the population of Pernambuco who live within just 2.8% of the state's territory. Urbanisation has progressed rapidly in the state but is now increasing at a slower pace. On average the population of the city grew at an annual rate of 0.78% between 2000 and 2010 (Secretaria de Desenvolvimento e Planejamento Urbano, 2010).

The road infrastructure of the metropolitan region of Recife has not kept up with the rapid population and economic growth, resulting in traffic congestion and crowded public transport. Traffic and transit are overwhelmingly identified as the main problem facing Recife, according to Architecture and Engineering National Union (Sinaenco) (da Letra, 2013). The transport sector is responsible for most carbon emissions (65.6%), followed by waste (19.3%), household energy (6.4%), industrial energy (4.9%), commercial/institutional energy (3.8%) and government (0.4%).

Recife is one of the most vulnerable cities in Brazil to the impacts of climate change. More than 80% of the urban area is within 30m of the coastline and the average elevation of the city is less than 4m above sea level. Under a scenario where sea levels rise 0.5m, it has been predicted that 39.32km2, or approximately 13.4% of the metropolitan area, would become a flood zone (Costa *et al.*, 2010).



Recife has implemented policies and schemes to help local communities and the environment. The city is conducting a long-term project, 'Recife 500 anos, a cidade que queremos' (Recife 500 years, the city we want), which ends in 2037 (CAU/PE, 2012). The initiative aims to improve social inclusion and accelerate human development through investing in urban spatial distribution and mobility systems, economic development, environmental sustainability and public services. Examples of urban planning initiatives under this umbrella include 'Parque Capibaribe – caminho das capivaras' (Capibaribe Park – Capybara's Path) and participation in the Brazilian project UrbanLEDS. The city is currently preparing municipal policies on low emission urban devleopment. We hope that this research will inform municipal policy design and support the city's climate and development goals.

### Aims and Objectives

What is the best way to shift a city to a more energy efficient, low carbon development path? It is important to demonstrate the local benefits of climate action to mobilise political commitment and engage a broad range of actors. Even where there is broad interest in such a transition, there are major obstacles that often prevent cities from acting on such a far-reaching 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 Recife, and to use this to examine whether there is an economic case that can be used to secure large-scale low carbon investment in the city. To do this, we map broad trends in energy use, energy expenditure and carbon emissions in Recife, and examine the implications of 'business as usual' development in the city. This provides a macro-level context to explore the value of low carbon measures. We also provide prioritised lists of the most cost- and carbon-effective measures that could realistically be promoted across the housing, commercial and public buildings, transport and waste sectors within the city. On this basis, the aim is to consider whether there is an economic case for major investments in energy efficiency, renewable energy and other low carbon measures across the city, and whether these investments have the potential to shift the city on to a lower cost, lower carbon development path.

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 government departments, development agencies, industry and civil society organisations to design climate strategies that exploit the most economically attractive measures. This 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 low carbon development.

# Chapter 2.
# Our Approach

### Baseline Analysis

The baseline drew extensively on the greenhouse gas emissions inventory for the City of Recife for 2012 using the methodology Global Protocol for Community-Scale Inventories, prepared by Local Governments for Sustainability (ICLEI) as part of the Urban LEDS project. This provided an overview of energy consumption by fuel type and consumer type. We then used state-level trends in energy consumption obtained from the Ministry of Mines and Energy to backcast the changing levels and composition of energy supply to, and demand in Recife. 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, with estimates of changing waste production based on population size and average per capita income.

We use this data to develop business as usual baselines based on the continuation of these trends through to 2030. These baselines allow us to predict future levels and forms of energy supply and demand, as well as future energy bills and carbon footprints. Calculations of the changing carbon intensity of electricity are based on planned investments in electricity generation. We compare all future activities against these baselines.

Lists of all of the participants in the expert workshops are presented in Appendix A, while a detailed explanations of the data sources, methods and assumptions used to develop the baseline scenario are presented in Appendix B.

### Identification and Assessment of Measures

We develop lists of all the energy efficiency, small-scale renewable energy technologies and other low carbon measures that could potentially be applied in the housing, commercial and public buildings, transport and waste sectors in the city. The industry sector was excluded from this stage to be consistent with the City Master Plan. The City of Recife limits the amount and types of industrial activity within the metropolitan area, and the remaining industries have a limited carbon footprint.

We include both technological and behavioural measures in our analysis. The long lists of all potential measures are drawn from extensive literature reviews and stakeholder consultations, and then we review these to remove any options that are not applicable in a Brazilian context. The outputs form our shortlists of measures for each sector. These shortlists are not necessarily exhaustive – some measures may have been overlooked, while others may not have been included 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 shortlists. 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 incorporate the changing carbon intensities of electricity (based on planned investments in the electricity sector) and assume an average annual rise of 2% 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 savings from adopting green building standards depend on whether there are also energy efficiency standards for air conditioners. Similarly, the energy savings from increasing use of bicycles depends on the impact on modal share of different forms of transport. To take these interactions into account, we calculate the impact of each measure if adopted independently with business as usual conditions in energy supply. These calculations underpin the figures in the league tables, our prioritised menus of different options. 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 energy savings from passive cooling schemes in buildings reduce the mitigation potential of more efficient air conditioners.

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. A detailed explanation of the data sources and assumptions used in the options appraisal is presented in Appendix C.

**Table 2. Lists of the low carbon measures considered.**

| Sector | Mitigation Measures |
|---|---|
| Commercial and public buildings | Air conditioners – energy efficiency standards, elevators and escalators – energy efficiency standards, green building standards, LED street lighting, building retrofit with double glazed glass and polystyrene insulation, setting LED targets, solar photovoltaic (PV) panels (a-Si), solar PV panels (HIT), turning off lights. |
| Domestic buildings | Air conditioners – energy efficiency standards, energy management of appliances, passive cooling systems in new buildings – evaporative cooling via porous roofs, passive cooling systems in new buildings – high albedo, refrigerator – energy efficiency standards, setting LED targets, solar-assisted electric showers, solar photovoltaic panels (a-Si), solar PV panels (HIT), television – energy efficiency standards, turning off lights, washing machines – energy efficiency standards. |
| Transport | BRT – East-West, BRT – North-South, BRT North-South and East-West capacity expansion, CNG taxis, CNG private vehicle targets, construction of bike lanes, converting existing bus fleet to biodiesel, converting existing bus fleet to hybrids by 2030, converting existing bus fleet to CNG by 2030, expansion of bike sharing scheme, EU carbon emission vehicle standards, increase in bus service, increase in CNG bus service, increase in hybrid bus service, investments to increase public transit use and safety, mandatory fuel efficiency labelling, metro expansion, street metering expansion, subsidy for scrapping old vehicles – cash, subsidy for scrapping old vehicles – hybrid voucher, teleworking. |
| Waste | Centralised composting, energy from waste (combined heat and power), energy from waste (electricity), home composting, hybrid waste collection retrofit, incineration, landfill gas (LFG) flaring, LFG utilisation, recycling program, waste prevention. |

### Assessment of the Scope for Deployment

We evaluate the potential scope for deploying each measure in Recife in the period to 2030. 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 and forms of energy consumption, or the scope for an option to reduce emissions from a particular waste stream.

Based on stakeholder consultations, we develop realistic and ambitious rates of deployment – with realistic rates being based on readily achievable levels of uptake, and ambitious rates assuming rates of deployment or uptake that could be achieved with supporting policies and favourable conditions in place. These assessments take into account the lifespans and renewal rates 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 deployment to participatory review in expert workshops to ensure that they are as realistic as possible. More detailed explanations of the data sources and assumptions used in the appraisal of low carbon options are presented in Appendix C.

### Aggregation 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 determine the combined impact of the measures on 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.

### Multi-criteria Analysis

Stakeholders identified by the authors and funders were invited to workshops being run in Recife and Sao Paulo. The participants represented policy, business and civil society communities (a full list of attendees is available in Appendix A). Four sessions were held: one for each of the domestic, public and commercial, transport and waste sectors. At each one, the participants were presented with a brief overview of the project and the goals of the multi-criteria analysis (MCA).

For each sector, participants were given a list of low carbon measures (some options were packaged together in order to reduce the overall number of measures being reviewed). The participants were then asked to assess each measure according to five broad criteria: political acceptability, public acceptability, capacity for implementation, positive impacts on human development and positive impacts on the environment. Participants indicated their perception of the measure by providing a score from 1 to 5 for each option, where 5 indicates that the option performs very well and 1 indicates that the option performs very poorly. Participants were also invited to consider if any of the measures needed to be amended or if any additional measures should be considered. When revisions were offered, participants were asked to rank the new measures as well as those originally presented.

In order to develop an overall ranking for each measure or cluster the participants were asked as a group to apportion a percentage weighting to each of the five criteria presented. The total score for each option or cluster of options was then calculated using the weighted average score.



# Chapter 3. The Key Findings

### The Changing Context and the Impacts of 'Business as Usual' Trends

Business as usual trends in Recife show significant decoupling of economic output and energy use between 2000 and 2030 (see Fig. 1). However, GDP and energy demand per capita are both rising steadily, while the population of Recife is also growing. These effects are offsetting recent improvements in energy intensity and leading to a net increase in energy use.

The electricity grid serving Recife depends largely on hydroelectricity. The real cost of energy in Brazil has not changed significantly since 2000. However, Brazilians enjoyed relatively cheap electricity in the early 2000s and faced more expensive energy over the last five years. We have therefore assumed an increase of 2% per annum for real energy prices to 2030. The rising real energy prices combined with increasing energy consumption means that, under business as usual conditions, the total energy bill for Recife will nearly triple from its 2014 level in the period to 2030 (see Fig. 2).

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

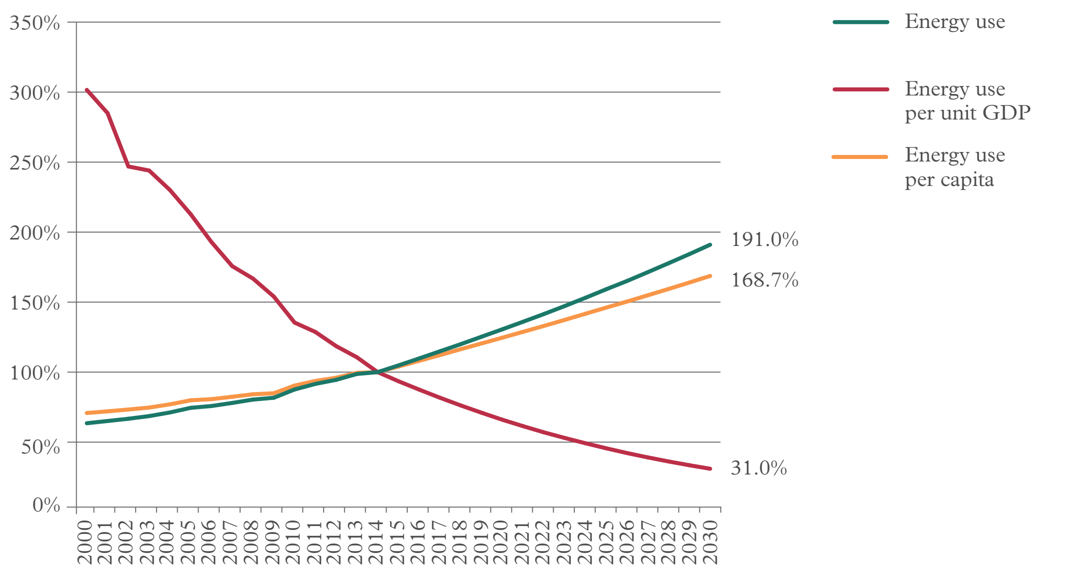



**Figure 2: Indexed energy prices and total energy bill. Since we assume that all energy prices rise at 2% per annum, all energy prices will increase by 37.3% between 2015 and 2030.**

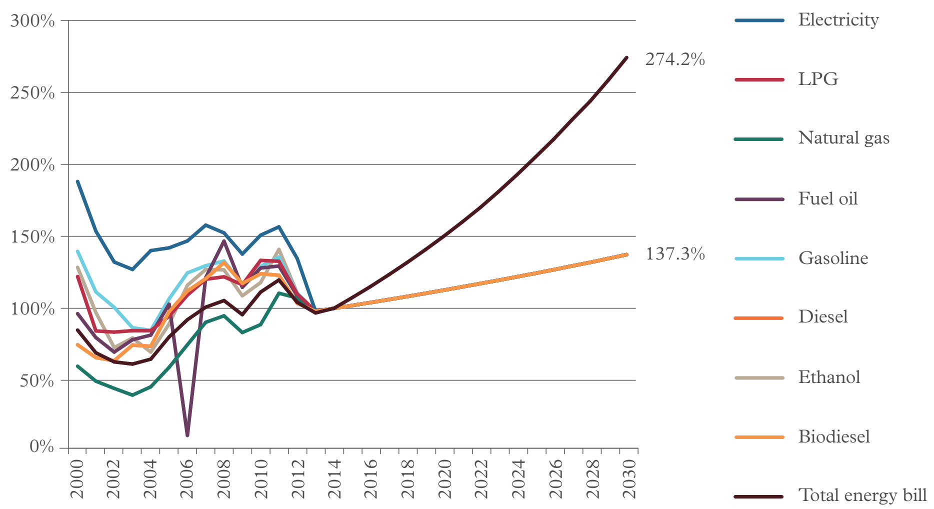
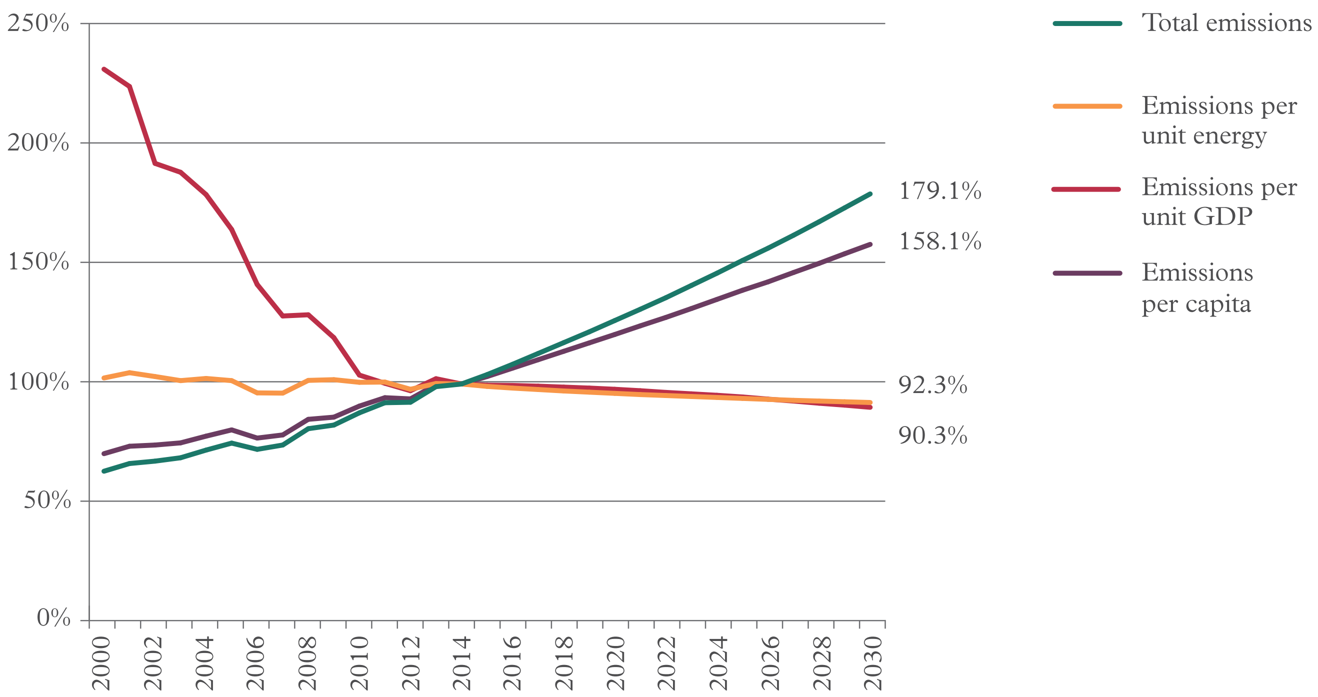


**Figure 3: Indexed emissions – total, per unit of energy, per unit of GDP and per capita.**




Despite a slight increase in the carbon intensity of electricity, fuel switching means that the carbon intensity of energy consumed by Recife is projected to decrease slightly to 2030. When this trend is combined with rapid economic growth, the emissions produced per unit of GDP will fall slightly between 2014 and 2030. The improvements in the carbon intensity of GDP are projected to slow due to falling economic growth rates and rapid growth of carbon-intensive transport in the city. It is important to note that, despite the fact that emission intensity per unit of energy and per unit of GDP are slowly falling, rapid economic and population growth will lead to a rapid rise in per capita emissions and total emissions attributed to the city. In a business as usual scenario, per capita emissions in Recife are therefore forecast to increase by 58.1% between 2014 and 2030 (see Fig. 3).

For the city of Recife, business as usual trends will lead total energy consumption to rise by 91.0% from 10.72 TWh in 2014 to a forecast level of 20.47 TWh in 2030 (see Fig. 4).

When combined with a projected increase in real energy prices of 2% per annum, this leads to the total expenditure on energy to increase by 174.2% from BRL 23.79 billion (USD 1.45 billion) in 2014 to a forecast level of BRL 46.18 billion (USD 3.97 billion) in 2030 (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 79.1% from 2.92 MtCO2-e in 2014 to a forecast level of 5.22 MtCO2-e in 2030 (see Fig. 6).



**Figure 4: Total energy use by sector in Recife, 2000 to 2030.**

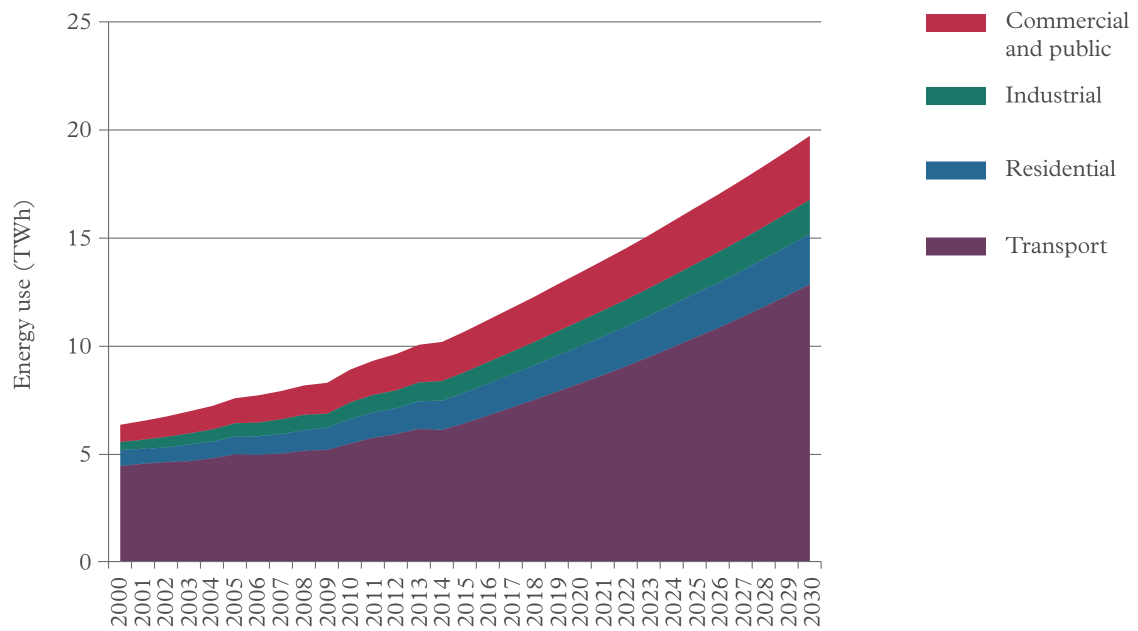



**Figure 5: Total energy expenditure by sector in Recife, 2000 to 2030.**

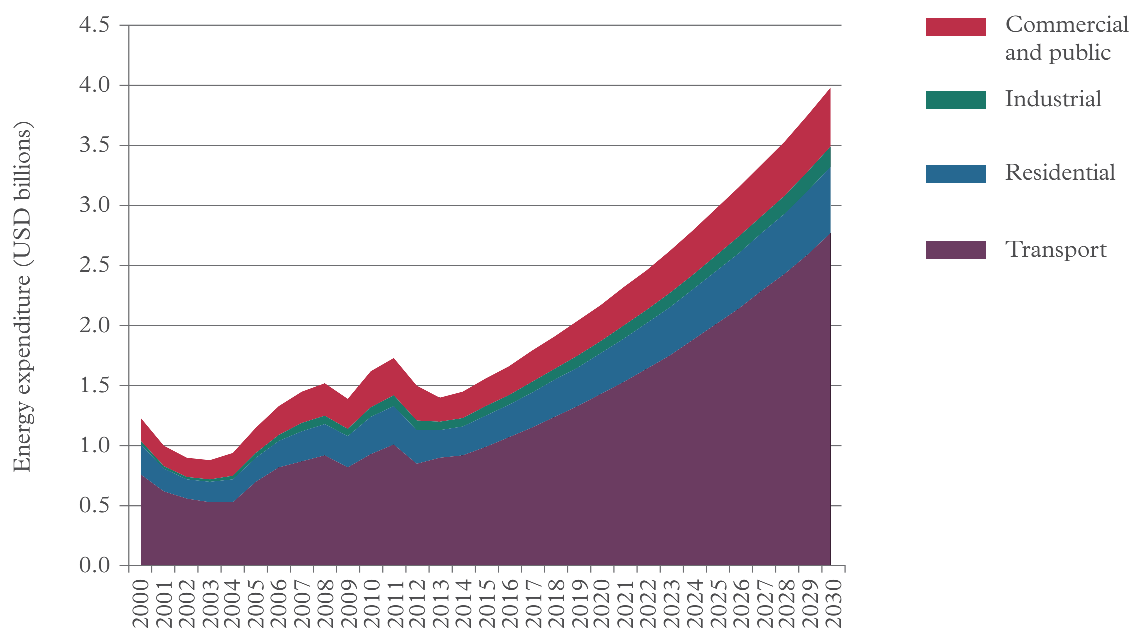
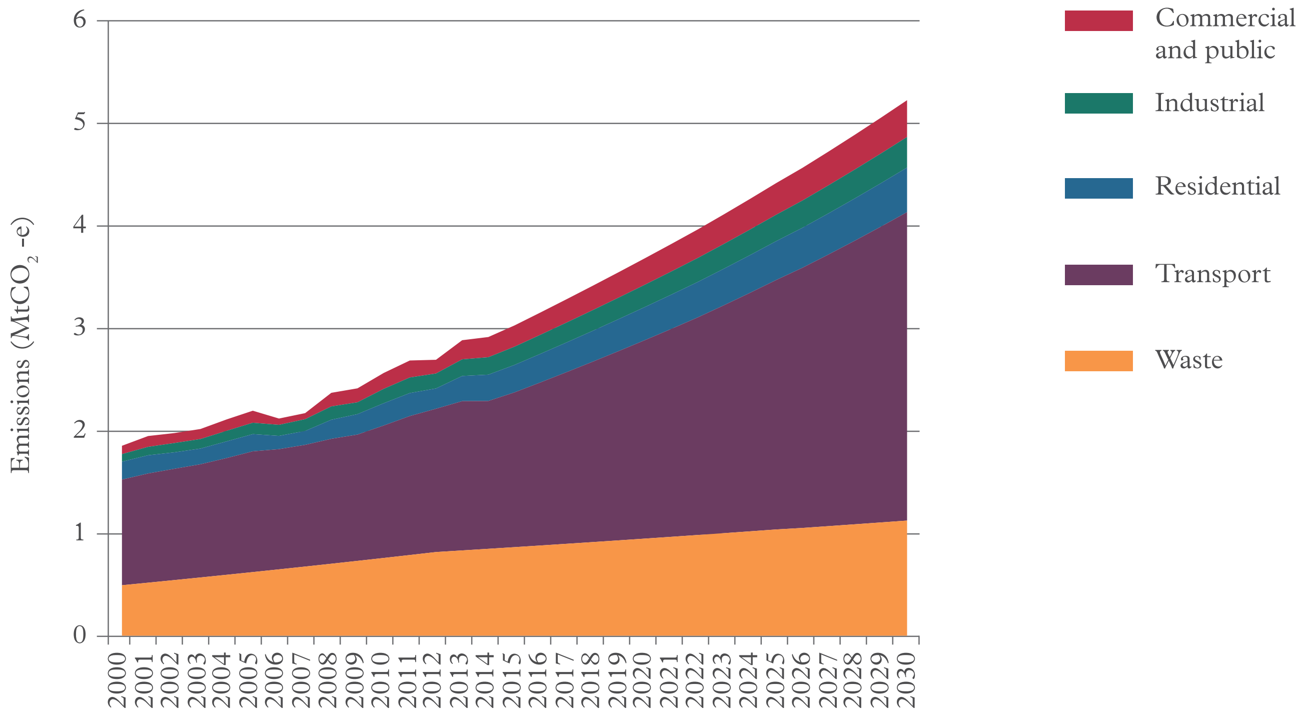


**Figure 6: Greenhouse gas emissions by sector in Recife, 2000 to 2030.**




## The Potential for Carbon Reduction – Investments and Returns

We find that – compared to business as usual trends – Recife could reduce their carbon emissions by 2030 by:

— 24.3% through cost-effective investments in the city that would more than pay for themselves on commercial terms over their lifetime. This would require an investment of BRL 7.79 billion (USD 3.32 billion), generating annual savings of BRL 1.37 billion (USD 585.25 billion), paying back the investment in 5.7 years and generating annual savings for the lifetime of the measures.

— 31.0% with cost-neutral measures that could be paid for by reinvesting the income generated from cost-effective measures. This would require an investment of BRL 14.91 billion (USD 6.35 billion), generating annual cost savings of BRL 1.35 billion (USD 575.01 billion), paying back the investment in 11.0 years and generating annual savings for the lifetime of the measures.



We find that the transport sector contains 58.1% of the total potential for cost-effective low carbon investments, with the remaining potential being distributed among the domestic sector (6.9%), the commercial sector (12.5%), and the waste sector (22.5%).

While the impacts of the cost-effective investments will reduce overall emissions relative to business as usual trends, they do not stop overall emissions from rising in absolute terms. With exploitation of all cost-effective options, by 2030 emissions would be 35.7% above 2014 levels. These measures will also save BRL 1.37 billion (USD 585.24 million) in energy expenditure each year, thereby reducing the energy bill in 2030 from a projected 12.1% of GDP to 8.6%. With the exploitation of all cost-neutral measures, the city's emissions rise by 23.7% above 2014 levels instead of by 79.1%.

However, investment in cost-effective and cost-neutral options can buy cities much needed time to lock in permanent reductions in emissions. If all cost-effective options are implemented, the Time to Reach BAU Emission Levels (TREBLE) relative to 2030 in Recife will be 22 years. If all cost-neutral measures are implemented, emissions will only reach their 2030 business as usual level in 43 years. In other words, economically neutral levels of investment in climate mitigation can keep emissions in Recife below business as usual trends for decades to come, giving policymakers time to build the political momentum and the technical, financial and institutional capabilities necessary for more ambitious changes to urban form and function.

**Figure 7: Emissions from Recife under three different scenarios, 2000 to 2030.**

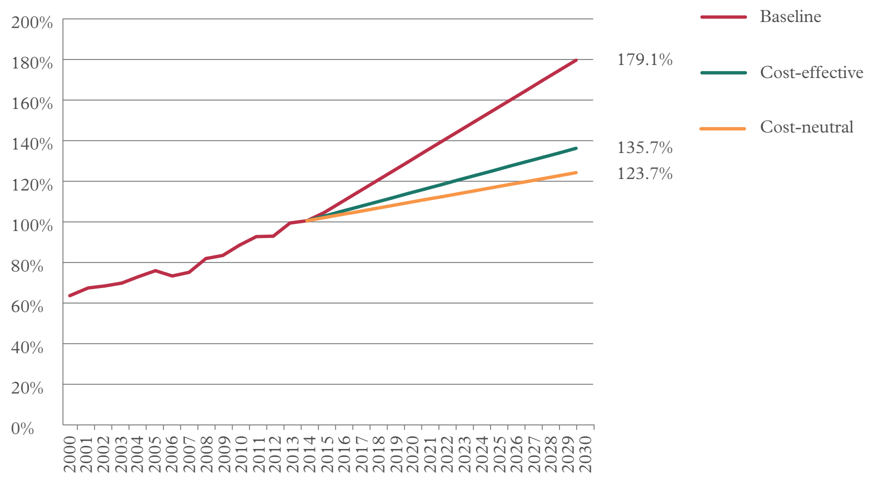
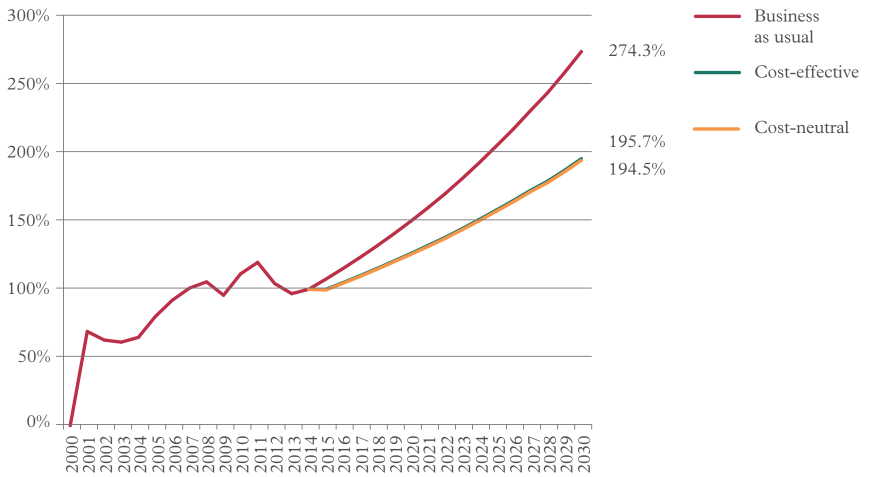



**Figure 8: Energy bills for Recife under three different investment scenarios, indexed to 2014 emissions, between 2000 and 2030**



# Chapter 4.
# Sector-Specific Findings

## Sector Focus

## The Commercial and Public Sector


### Introduction

The commercial and public sector is responsible for 83% of Recife's economy (World Bank, 2011), and for 17% of the city's energy consumption. While the sector consumes some LPG, oil and natural gas, electricity is overwhelmingly the main source of energy. The commercial and public sector includes electricity sold under the 'commercial', 'public power', 'public service', 'public lighting' and 'traffic signs' tariffs. Businesses are by far the largest users of energy within this sector. In 2012, the commercial and public sector was responsible for 17.4% of all energy consumed, 18.7% of the city's energy bill and 6.9% of the city's greenhouse gas emissions (excluding emissions from air and water transport, which fall outside the municipal authorities' powers) (ICLEI, 2014).

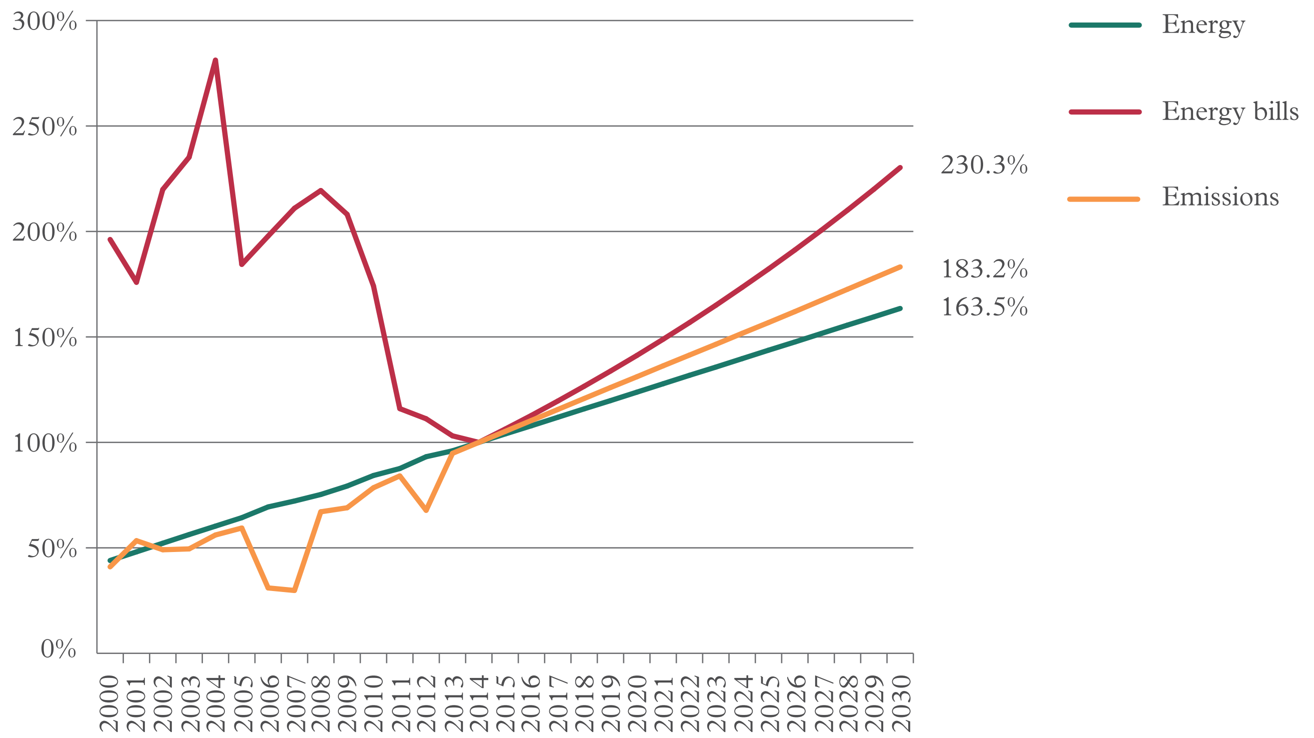
### The Impacts of 'Business as Usual' Trends

Growth of the tertiary sector leads commercial sector energy consumption to rise by 63.5% from 1.81 TWh in 2014 to a forecast level of 2.96 TWh in 2030.

When combined with increasing real energy prices, this leads to the total spend from the commercial and public sector on energy to increase by 126.5% from BRL 506.49 million (USD 215.76 million) in 2014 to a forecast level of BRL 1.15 billion (USD 488.61 million) in 2030.

When combined with increasing levels of carbon emissions per unit of energy consumed, this leads to carbon emissions attributed to commercial and public consumption increasing by 82.3% from 196.64 ktCO2-e in 2014 to a forecast level of 358.53 ktCO2-e in 2030.

**Figure 9. Commercial sector: indexed energy use, energy bills and emissions**

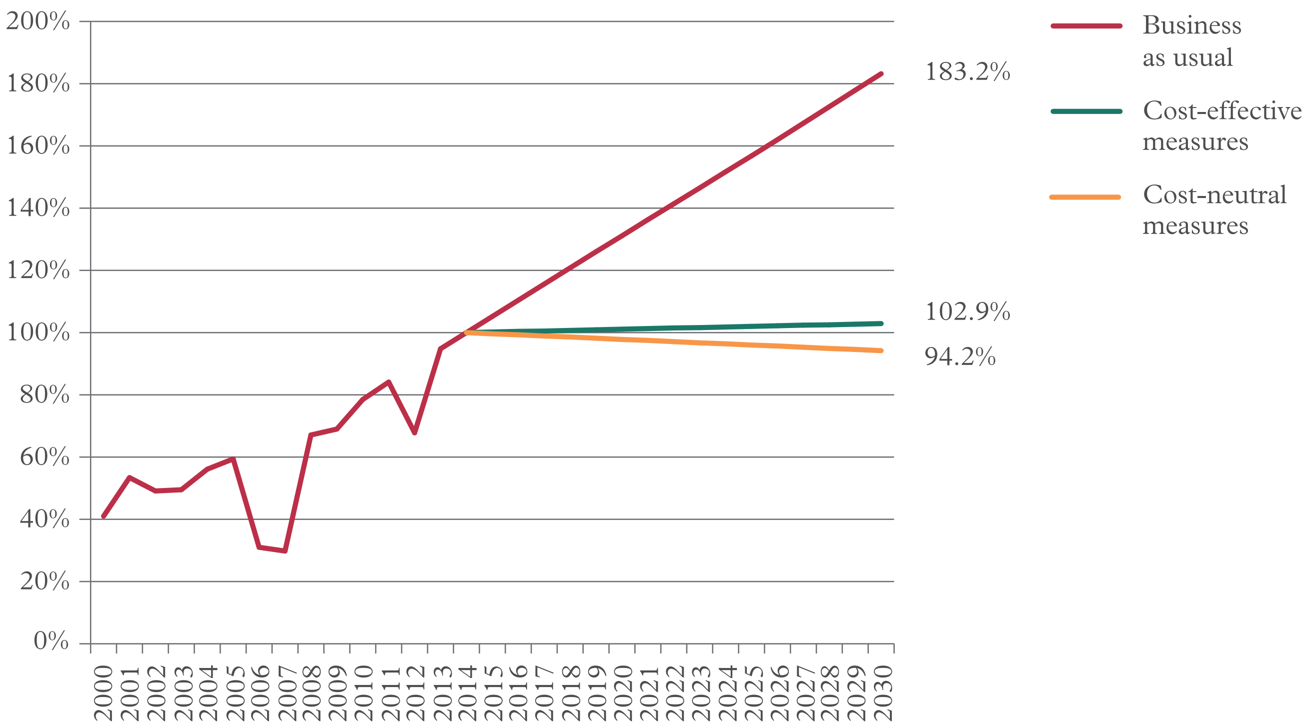


### The Potential for Carbon Reduction – Investments and Returns

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

- 25.4% through cost-effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of BRL 2.71 billion (USD 1.15 billion), generating annual savings of BRL 129.00 million (USD 54.91 million), paying back the investment in 21.0 years and generating annual savings for the lifetime of the measures.
- 31.7% through cost-neutral investments that could be paid for by re-investing the income generated from the cost-effective measures. This would require investment of BRL 5.41 billion (USD 2.31 billion), generating annual savings of BRL 171.99 million (USD 73.22 million), paying back the investment in 31.5 years and generating annual savings for the lifetime of the measures.

**Figure 10. Emissions from the commercial sector under three different investment scenarios, indexed against 2014 emissions, between 2000 and 2030.**






Cost effective

Cost neutral

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

### Options Appraisal

**Table 3. League table of the cost-effectiveness of low carbon measures in the commercial and public sector (BRL/t$CO_2$-e and USD/t $CO_2$-e).**

| Rank | Measure: | BRL /t$CO_2$-e | USD /t$CO_2$-e |
|---|---|---|---|
| 1 | Air conditioner (EE Standard 1) | -9,887.01 | -4,208.90 |
| 2 | Air conditioner (EE Standard 2) | -8,040.84 | -3,422.99 |
| 3 | Turning off indoor lights | -2,035.23 | -866.40 |
| 6 | LED street lighting | -1,840.90 | -783.67 |
| 7 | LED target (commercial buildings) | -557.94 | -237.51 |
| 8 | Setting LED target (public buildings) | -388.49 | -165.38 |
| 9 | Elevators and escalators (EE Standard 1) | -1.84 | -0.78 |
| 10 | Elevators and escalators (EE Standard 2) | -1.84 | -0.78 |
| 11 | a-Si solar PV panel | 19.93 | 8.48 |
| 12 | HIT solar PV panel | 219.70 | 93.53 |
| 13 | Green Building Standard 2 | 2,536.82 | 1,079.93 |
| 14 | Green Building Standard 1 | 2,960.27 | 1,260.19 |
| 15 | Double glazed reflective glass plus polystyrene insulation (commercial buildings) | 18,770.55 | 7,990.62 |
| 16 | Double glazed reflective glass plus polystyrene insulation (public buildings) | 18,774.74 | 7,992.41 |

Cost effective

Cost neutral

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

**Table 4. League table of the carbon-effectiveness of low carbon measures in the commercial and public sector ($ktCO_2$-e).**

| Rank | Measure: | $ktCO_2$-e (2015-2013) |
|---|---|---|
| 1 | Air conditioner (EE Standard 2) | 393.52 |
| 2 | Air conditioner (EE Standard 1) | 393.52 |
| 3 | Green Building Standard 2 - 100% of new buildings | 121.55 |
| 4 | LED target (commercial buildings) - 100% by 2030 | 109.09 |
| 5 | Turning off indoor lights | 66.41 |
| 6 | Green Building Standard 2 - 50% of new buildings | 60.77 |
| 7 | Green Building Standard 1 - 100% of new buildings | 60.77 |
| 8 | Green Building Standard 1 - 50% of new buildings | 30.39 |
| 9 | HIT solar PV panel - target of additional 20MW by 2030 | 27.63 |
| 10 | HIT solar PV panel - target of additional 10MW by 2030 | 13.81 |
| 11 | Double glazed reflective glass plus polystyrene insulation - retrofit 20% of commercial buildings | 13.76 |
| 12 | Elevators and escalators (EE Standard 2) | 13.37 |
| 13 | LED street lighting | 11.64 |
| 14 | a-Si solar PV panel - additional 20MW by 2030 | 10.24 |
| 15 | LED target (public buildings) - 100% by 2030 | 7.84 |
| 16 | Double glazed reflective glass plus polystyrene insulation - retrofit 10% of commercial buildings | 6.88 |
| 17 | Elevators and escalators (EE Standard 1) | 6.69 |
| 18 | a-Si solar PV panel - additional 10MW by 2030 | 5.12 |
| 19 | Double glazed reflective glass plus polystyrene insulation - retrofit 100% of public buildings | 5.06 |
| 20 | Double glazed reflective glass plus polystyrene insulation - retrofit 50% of public buildings | 2.53 |



## Sector Focus

# The Residential Sector

## Introduction

Rapid improvements in living standards are both causing and caused by increasing energy use by the residential sector in Recife. Refrigerators, freezers and lighting are the most significant end-users of electricity in the Northeast region, with growing demand driven by increasing ownership of air conditioners and electric showers (Ghisi et al., 2007). The demand for non-electricity forms of energy is predominately for cooking. In 2012, the residential sector was responsible for 12.8% of all energy consumed, 19.8% of the city's energy bill and 9.3% of the city's greenhouse gas emissions (excluding emissions from air and water transport, which fall outside the municipal authorities' powers) (ICLEI, 2014).

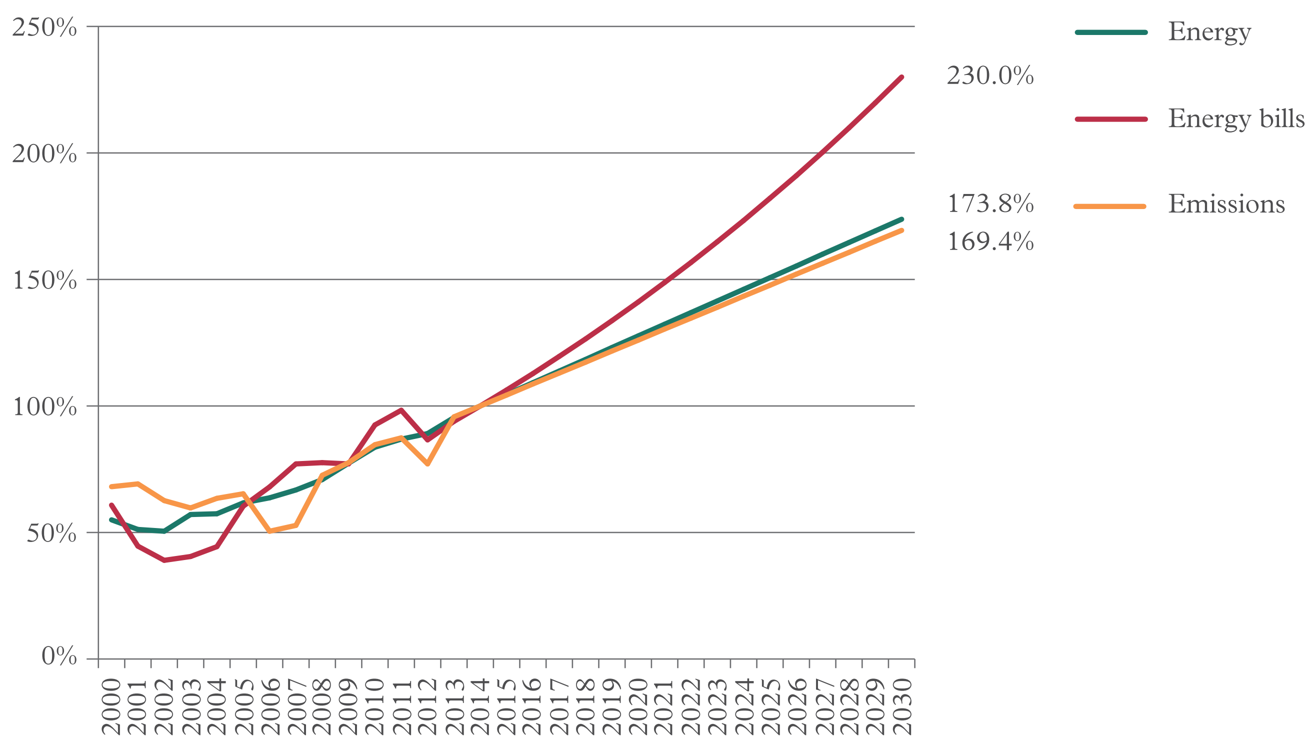
## The Impacts of 'Business as Usual' Trends

For the residential sector, background trends suggest substantial growth both in the number of households and in the average levels of energy consumption per household. Domestic sector energy consumption is projected to rise by 62.9% from 1.93 TWh in 2014 to a forecast level of 3.15 TWh in 2030.

When combined with increasing real energy prices, this leads to the total expenditure from the domestic sector on energy to increase by 125.6% from BRL 572.56 million (USD 243.90 million) in 2014 to a forecast level of BRL1.29 billion (USD 550.34 million) in 2030.

Rapid increases in household electricity consumption combined with the increasing carbon intensity of the grid leads to carbon emissions attributed to the domestic sector increasing by 69.4% from 256.27 ktCO2-e in 2014 to a forecast level of 434.15 ktCO2-e in 2030.

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





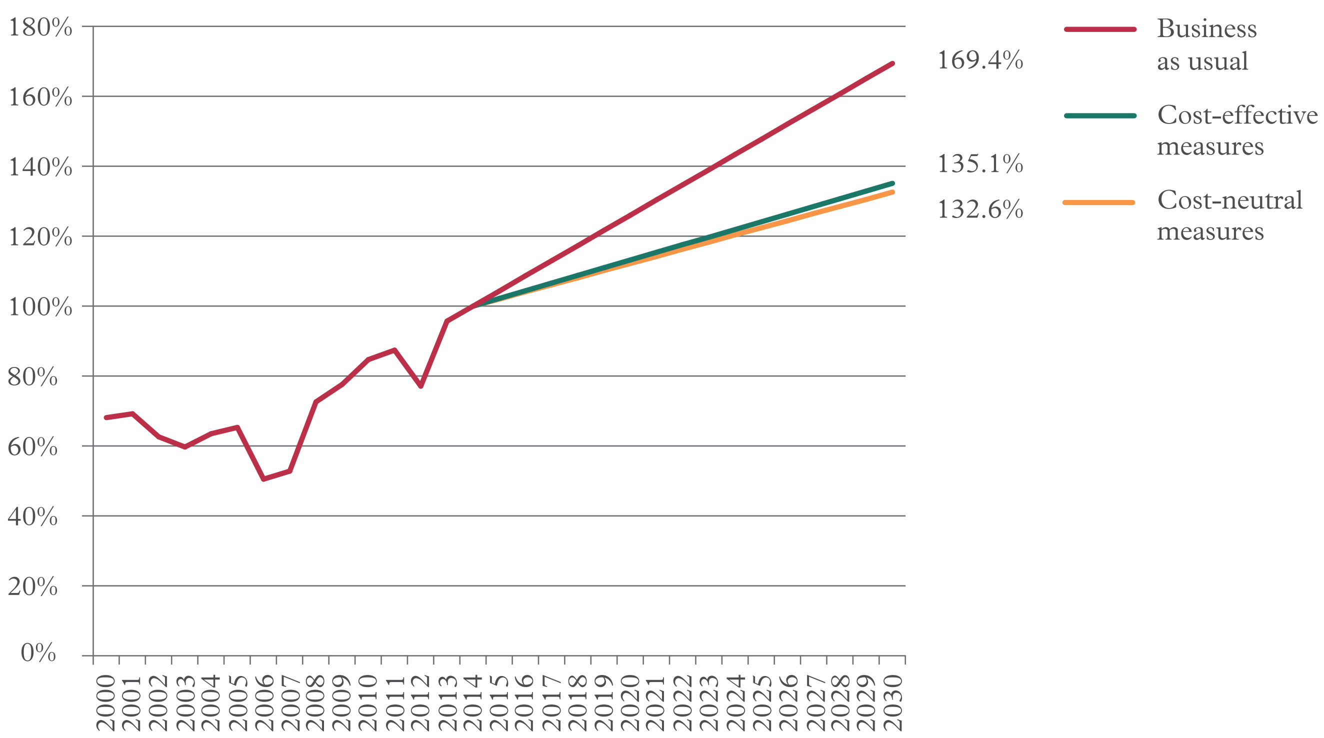

## The Potential for Carbon Reduction – Investments and Returns

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

— 20.3% through cost-effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of BRL 995.08 million (USD 423.60 million), generating annual savings of BRL 253.11 million (USD 107.75 million), paying back the investment in 3.9 years and generating annual savings for the lifetime of the measures.

— 21.8% through cost-neutral investments that could be paid for by re-investing the income generated from the cost-effective measures. This would require investment of BRL 1.88 billion (USD 799.16 million), generating annual savings of BRL 271.82 million (USD 115.71 million), paying back the investment in 6.9 years and generating annual savings for the lifetime of the measures.

**Figure 12. Emissions from the residential sector in three different investment scenarios, indexed to 2014 emissions, between 2000 and 2030**



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



Table 5. League table of the cost-effectiveness of low carbon measures in the residential sector ($BRL/tCO_2$-e and $USD/tCO_2$-e).

| Rank | Measure: | BRL /$tCO_2$-e | USD /$tCO_2$-e |
|---|---|---|---|
| 1 | Passive cooling (evaporative cooling via porous roofs) | -3,106.72 | -1,322.53 |
| 2 | Refrigerator (EE Standard 2) | -2,905.38 | -1,236.82 |
| 3 | Turning off lights | -2,354.33 | -1,002.24 |
| 6 | Passive cooling (high albedo) | -1,920.56 | -817.58 |
| 7 | Passive cooling (high albedo and evaporative cooling via porous roofs) | -1,811.97 | -771.36 |
| 8 | Air conditioner (EE Standard 1) | -1,052.05 | -447.86 |
| 9 | Air conditioner (EE Standard 2) | -1,001.20 | -426.21 |
| 10 | a-Si solar PV panel | -275.90 | -117.45 |
| 11 | Setting LED target of 50% | -113.91 | -48.49 |
| 12 | HIT solar PV panel | -76.13 | -32.41 |
| 13 | Energy management of appliances | -2.28 | -0.97 |
| 14 | Television (EE Standard 2) | -0.11 | -0.05 |
| 15 | Television (EE Standard 1) | -0.09 | -0.04 |
| 16 | Passive cooling (thermal insulation) | 2,274.09 | 968.08 |
| 17 | Solar-assisted electric shower | 3,291.01 | 1,400.98 |
| 18 | Refrigerator (EE Standard 1) | 1,680.09 | 715.22 |
| 19 | Washing machine (EE Standard 1) | 30,404.01 | 12,942.99 |
| 20 | Washing machine (EE Standard 2) | 30,404.01 | 12,942.99 |

Table 6. League table of the carbon-effectiveness of low carbon measures in the residential sector ($ktCO_2$-e).

| Rank | Measure: | $ktCO_2$-e (2015-2030) |
|---|---|---|
| 1 | HIT solar PV panel – 10% of households by 2030 | 225.56 |
| 2 | Air conditioner (EE Standard 2) | 212.11 |
| 3 | Air conditioner (EE Standard 1) | 169.33 |
| 4 | Energy management of appliances | 157.31 |
| 5 | HIT solar PV panel – 5% of households by 2030 | 112.78 |
| 6 | Turning off lights | 100.77 |
| 7 | Refrigerator (EE Standard 2) | 93.87 |
| 8 | a-Si solar PV panel – 10% of households by 2030 | 83.59 |
| 9 | Television (EE Standard 2) | 66.11 |
| 10 | Television (EE Standard 1) | 61.35 |
| 11 | Passive cooling (high albedo and evaporative cooling via porous roofs) – 100% of new buildings | 54.56 |
| 12 | a-Si solar PV panel – 5% of households by 2030 | 41.80 |
| 13 | Solar-assisted electric shower – 40% of households | 39.99 |
| 14 | Passive cooling (high albedo) – 100% of new buildings | 34.18 |
| 15 | Passive cooling (thermal insulation) - 100% of new buildings | 32.98 |
| 16 | LED target – 50% | 29.09 |
| 17 | Passive cooling (evaporative cooling via porous roofs) – 50% of new buildings | 21.29 |
| 18 | Solar-assisted electric shower – 20% of households | 19.99 |
| 19 | Refrigerator (EE Standard 1) | 19.72 |
| 20 | Passive cooling (high albedo and evaporative cooling via porous roofs) – 50% of new buildings | 17.09 |
| 21 | Passive cooling (high albedo) - 50% of new buildings | 17.09 |
| 22 | Passive cooling (thermal insulation) – 50% of new buildings | 16.49 |
| 23 | Passive cooling (evaporative cooling via porous roofs) – 100% of new buildings | 15.56 |
| 24 | Washing machine (EE Standard 2) | 2.89 |
| 25 | Washing machine (EE Standard 1) | 1.45 |

Sector Focus

# The Industrial Sector



## Introduction

Pernambuco is the largest industrial centre in the Northeast of Brazil. Major industries in the region include agricultural processing for the region's sugarcane, cotton and tobacco crops, manufacturing of textiles, leather goods, electronics and pharmaceuticals, oil refining and support industries, as well as tertiary industries such as information communication technologies. Natural gas is the most significant source of energy, followed by electricity. Background trends and planned investments suggest an ongoing expansion of industry and consequently, industrial energy use. However, most industrial activity is concentrated in Recife's hinterland rather than within municipal boundaries. In 2012, the industrial sector was responsible for 9.0% of all energy consumed, 5.5% of the city's energy bill and 6.3% of the city's greenhouse gas emissions (excluding emissions from air and water transport, which fall outside the municipal authorities' powers) (ICLEI, 2014).

## The Impacts of 'Business as Usual' Trends

Industrial sector energy consumption is projected to rise by 72.1% from 954.5 GWh in 2014 to a forecast level of 1.57 TWh in 2030.

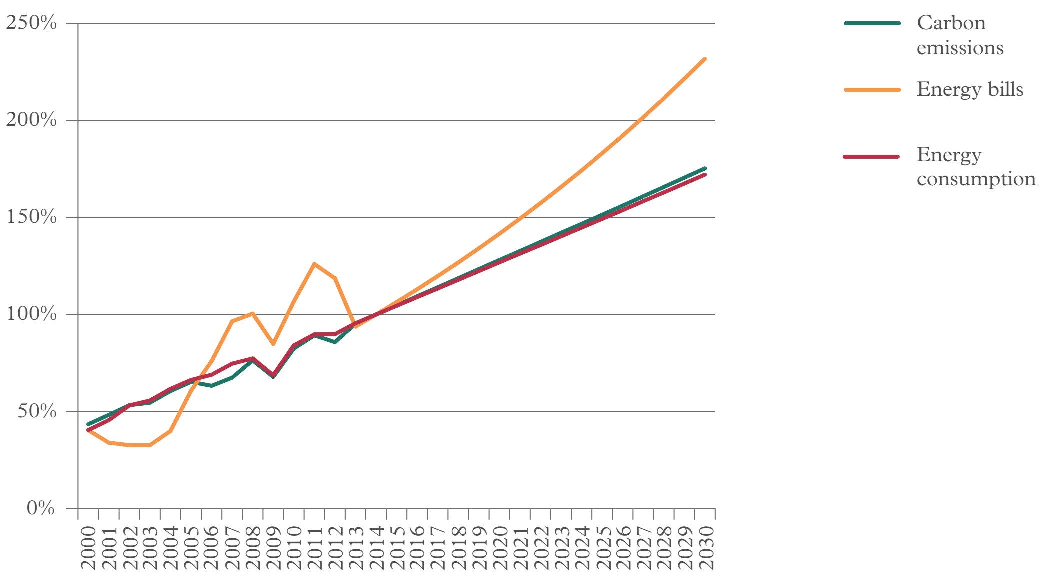
When combined with increasing real energy prices, this leads to the total expenditure from the industrial sector on energy to increase by 129.3% from BRL 225.08 million (USD 101.88 million) in 2014 to a forecast level of BRL 516.01 million (USD 219.81 million) in 2030.

Rapid increases in industrial energy consumption combined with the increasing carbon intensity of the grid leads to carbon emissions attributed to the industrial sector increasing by 75.3% from 169.99 ktCO2-e in 2014 to a forecast level of 297.92 ktCO2-e in 2030.

## The Potential for Carbon Reduction – Investments and Returns

We have not assessed low carbon measures for the industry sector for two reasons. Firstly, we have not been able to obtain data about the composition of energy use by industrial sector, so we cannot assess the scale of opportunities available. Secondly, the main industries within the boundaries of Recife are not very carbon-intensive (for example, no cement manufacturing or steel production). This means that there is less information available about the type of energy efficiency and other low carbon measures available within these industries. However, we do not believe this will be significant since the most significant opportunities in terms of emission reductions are likely to be found in high emitting sectors, particularly transport in the case of Recife.

**Figure 13. Industrial sector: indexed energy use, energy bills and emissions between 2000 and 2030**



Sector Focus

# The Transport Sector

## Introduction

Recife is a major hub for air, sea, rail and road transport. The transport sector is unsurprisingly a major source of emissions despite ambitious national policies to promote a shift to biofuels. Sales of light vehicles in Brazil are now dominated by flex-fuel models that can use any blend of ethanol and gasoline, which will help to reduce the carbon intensity of transport in Recife. The city is also well-serviced by public transport including buses, trains, a metro system and an expanding bus rapid transit network (BRT) although the proportion of trips by public transport has declined with rising car ownership (World Bank and PPPIAF, 2006). In 2012, land transport was responsible for 60.8% of all energy consumed, 56.0% of the city's energy bill and 53.3% of the city's greenhouse gas emissions (excluding emissions from air and water transport, which fall outside the municipal authorities' powers) (ICLEI, 2014).

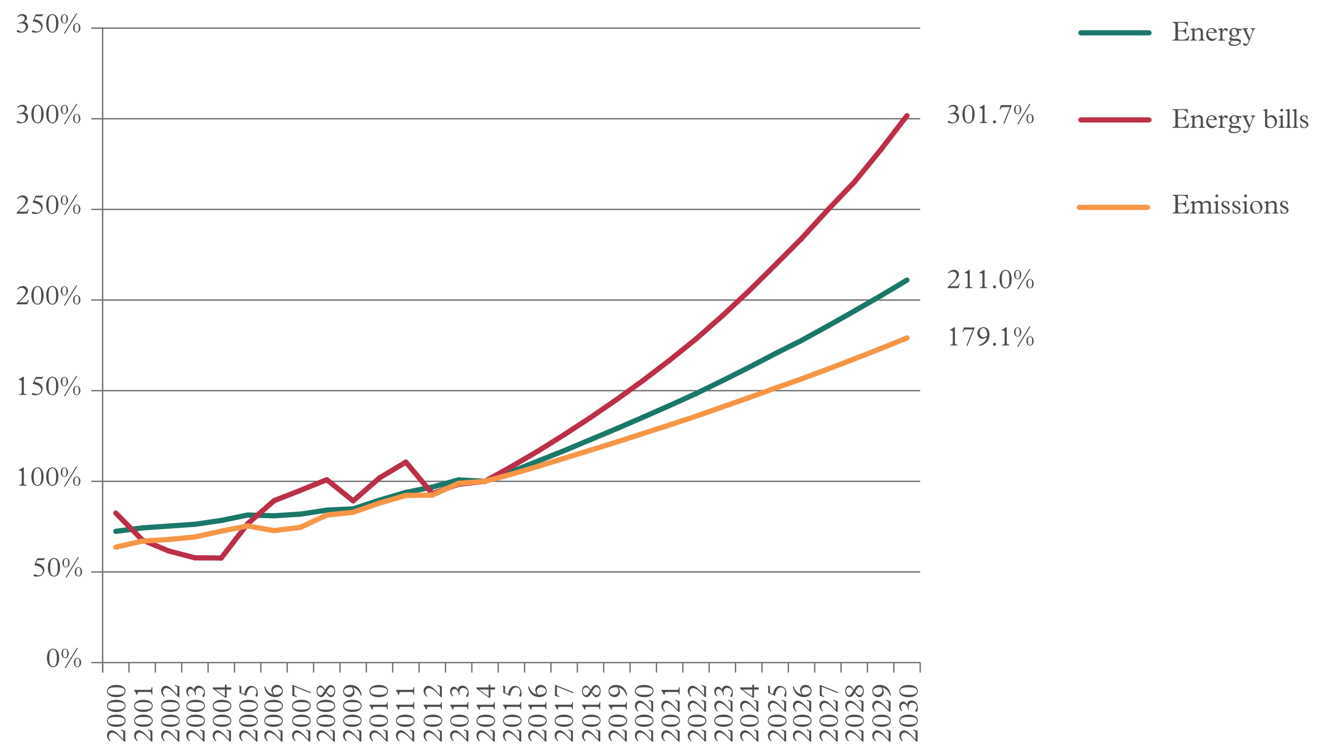
## The Impacts of 'Business as Usual' Trends

In the transport sector, background trends suggest a substantial growth in the vehicle fleet in Recife. Growth in vehicle numbers leads transport sector energy consumption to rise by 111.0%, from 6.38 TWh per year in 2014 to a forecast level of 12.79 TWh in 2030.

When combined with increasing real energy prices, this leads to total expenditure on energy from transport to increase by 201.8% from BRL 2.15 billion (USD 916.40 million) in 2014 to a forecast level of BRL 6.49 billion (USD 2.77 billion) in 2030.

Rapid growth in vehicle ownership is projected to lead to carbon emissions from the transport sector increasing by 108.8%, from 1.44 MtCO2-e in 2014 to a forecast level of 3.01 MtCO2-e in 2030.

**Figure 14. Transport sector: indexed energy use, energy bills and emissions**

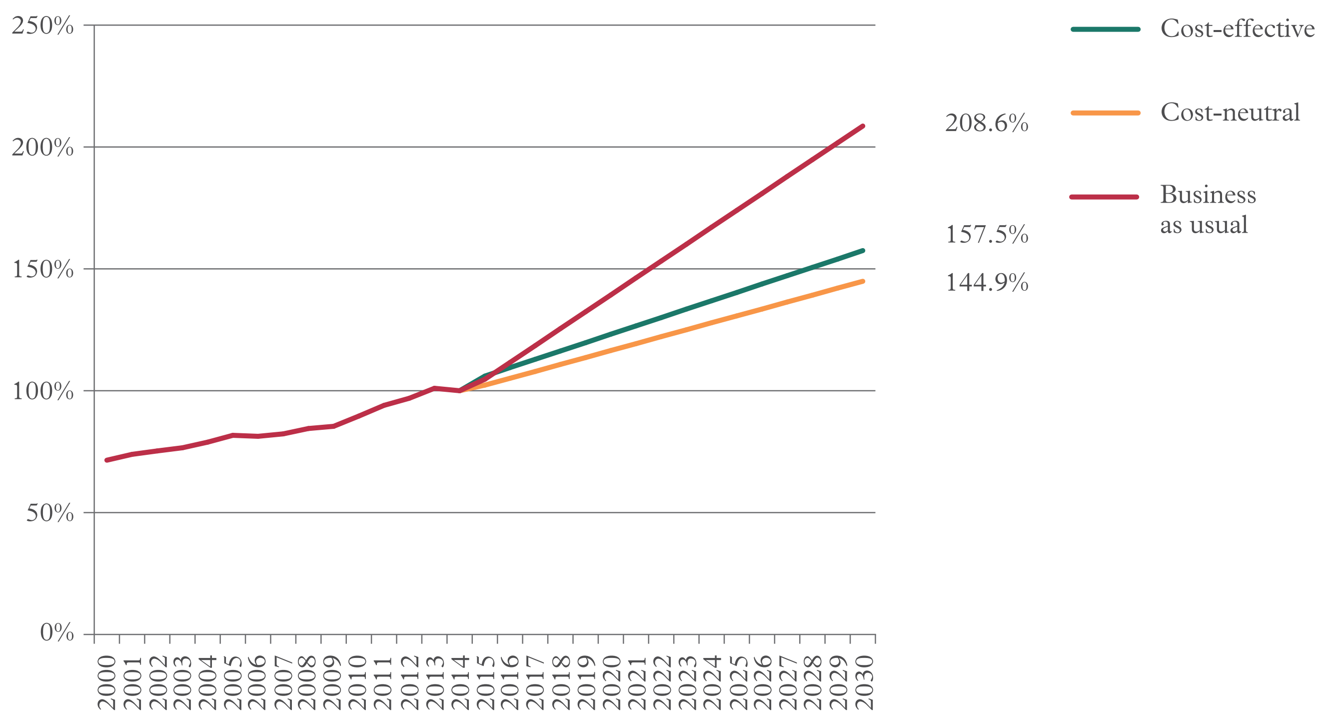


## The Potential for Carbon Reduction – Investments and Returns

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

- 24.5% through cost-effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of BRL 3.27 billion (USD 1.39 billion), generating annual savings of BRL 834.33 million (USD 355.17 million), paying back the investment in 3.9 years and generating annual savings for the lifetime of the measures.
- 30.5% through cost-neutral investments that could be paid for by re-investing the income generated from the cost-effective measures. This would require investment of BRL 6.59 billion (USD 2.80 billion), generating annual savings of BRL 740.94 million (USD 315.42 million), paying back the investment in 8.9 years and generating annual savings for the lifetime of the measures.

**Figure 15. Emissions from the transport sector under three different investment scenarios, indexed to 2014 emissions, between 2000 and 2030.**






Cost effective

Cost neutral

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

## Options Appraisal

**Table 7. League table of the cost-effectiveness of low carbon measures in the transport sector ($BRL/tCO_2$-e and $USD/tCO_2$-e).**

| Rank | Measure: | BRL $/tCO_2$-e | USD $/tCO_2$-e |
|---|---|---|---|
| 1 | Converting 2000 taxis to CNG by 2030 | -2,141.76 | -911.75 |
| 2 | Increase in CNG bus service - 40% | -1,468.21 | -625.02 |
| 3 | Increase in CNG bus service - 20% | -1,406.15 | -598.60 |
| 4 | CNG vehicles - 10% by 2030 | -1,347.99 | -573.84 |
| 5 | Increase in hybrid bus service - 20% | -477.52 | -203.28 |
| 6 | Increase in hybrid bus service - 40% | -426.64 | -181.62 |
| 7 | EU carbon emission vehicle standards | -425.43 | -181.11 |
| 8 | Mandatory fuel efficiency labelling | -368.98 | -157.07 |
| 9 | Converting existing bus fleet to CNG by 2030 | -302.45 | -128.76 |
| 10 | BRT - North-South | -254.48 | -108.33 |
| 11 | Teleworking | -223.75 | -95.25 |
| 12 | Street metering expansion | -209.43 | -89.15 |
| 13 | BRT - East-West | -163.67 | -69.67 |
| 14 | Converting existing bus fleet to hybrids by 2030 | -112.41 | -47.85 |
| 15 | Bike sharing - 2x current scheme | -2.76 | -1.17 |
| 16 | Subsidy for scrapping old vehicles - hybrid voucher valued at USD1,000 | 151.32 | 64.42 |
| 17 | Converting existing bus fleet to biodiesel | 214.35 | 91.25 |
| 18 | Bike lanes - 56km | 250.73 | 106.74 |
| 19 | Investments to increase public transit use and safety | 794.91 | 338.39 |
| 20 | BRT North-South and East-West capacity expansion | 931.66 | 396.61 |
| 21 | Subsidy for scrapping old vehicles – cash payments | 1,079.96 | 459.74 |
| 22 | Increase in bus service - 20% | 3,423.62 | 1,457.44 |
| 23 | Metro expansion | 25,129.48 | 10,697.62 |

Cost effective

Cost neutral

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

Table 8. League table of the carbon-effectiveness of low carbon measures in the transport sector ($ktCO_2$-e).

| Rank | Measure: | $ktCO_2$-e |
|---|---|---|
| 1 | Converting existing bus fleet to biodiesel | 7,467.92 |
| 2 | EU carbon emission vehicle standards | 4,140.15 |
| 3 | Converting existing bus fleet to hybrids by 2030 | 3,006.82 |
| 4 | Converting existing bus fleet to CNG by 2030 | 1,435.40 |
| 5 | Increase in hybrid bus service - 40% | 686.60 |
| 6 | Street metering expansion | 654.47 |
| 7 | Increase in CNG bus service - 40% | 394.16 |
| 8 | Increase in hybrid bus service - 20% | 373.89 |
| 9 | Increase in CNG bus service - 20% | 224.41 |
| 10 | BRT - North-South | 111.80 |
| 11 | BRT - East-West | 96.94 |
| 12 | Bike lanes - 56km | 94.35 |
| 13 | Bike sharing - 2x current scheme | 78.63 |
| 14 | Metro Expansion | 78.33 |
| 15 | Converting 2000 taxis to CNG by 2030 | 72.04 |
| 16 | Increase in bus service - 20% | 67.00 |
| 17 | Investments to increase public transit use and safety | 62.90 |
| 18 | Subsidy for scrapping old vehicles - hybrid voucher (1000 USD) | 39.48 |
| 19 | BRT North-South and East-West capacity expansion | 20.33 |
| 20 | CNG vehicles - 10% by 2030 | 18.69 |
| 21 | Subsidy for scrapping old vehicles (1000 USD) | 13.83 |
| 22 | Mandatory fuel efficiency labelling | 11.85 |
| 23 | Teleworking | 0.54 |



Sector Focus

# The Waste Sector

### Introduction

Population and economic growth are projected to lead to a significant increase in waste generation in Recife. Waste output is estimated to exceed a million tonnes per year in 2025, dominated by household waste. Currently, less than 2% of waste in Recife is recycled and the remaining 98% is destined for landfills. In 2012, the waste sector was responsible for 24.1% of the city's greenhouse gas emissions (excluding emissions from air and water transport, which fall outside the municipal authorities' powers) (ICLEI, 2014).

### The Impacts of 'Business as Usual' Trends

The rapid growth is projected to lead to carbon emissions from the waste sector increasing by 22.0%, from 855.22 ktCO2-e in 2014 to a forecast level of 1130.20 ktCO2-e in 2030 (see Fig. 5).

### The Potential for Carbon Reduction – Investments and Returns

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

— 25.2% through cost-effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of BRL 811.04 million (USD 345.26 million), generating annual savings of BRL 158.35 million (USD 67.41 million), paying back the investment in 5.1 years and generating annual savings for the lifetime of the measures.

— 38.1% through cost-neutral investments that could be paid for by re-investing the income generated from the cost-effective measures. This would require investment of BRL 1.03 billion (USD 440.17 million), generating annual savings of BRL 165.98 million (USD 70.66 million), paying back the investment in 6.2 years and generating annual savings for the lifetime of the measures.

**Figure 16: Emissions from the waste sector (MtCO2-e) between 2000 and 2030**

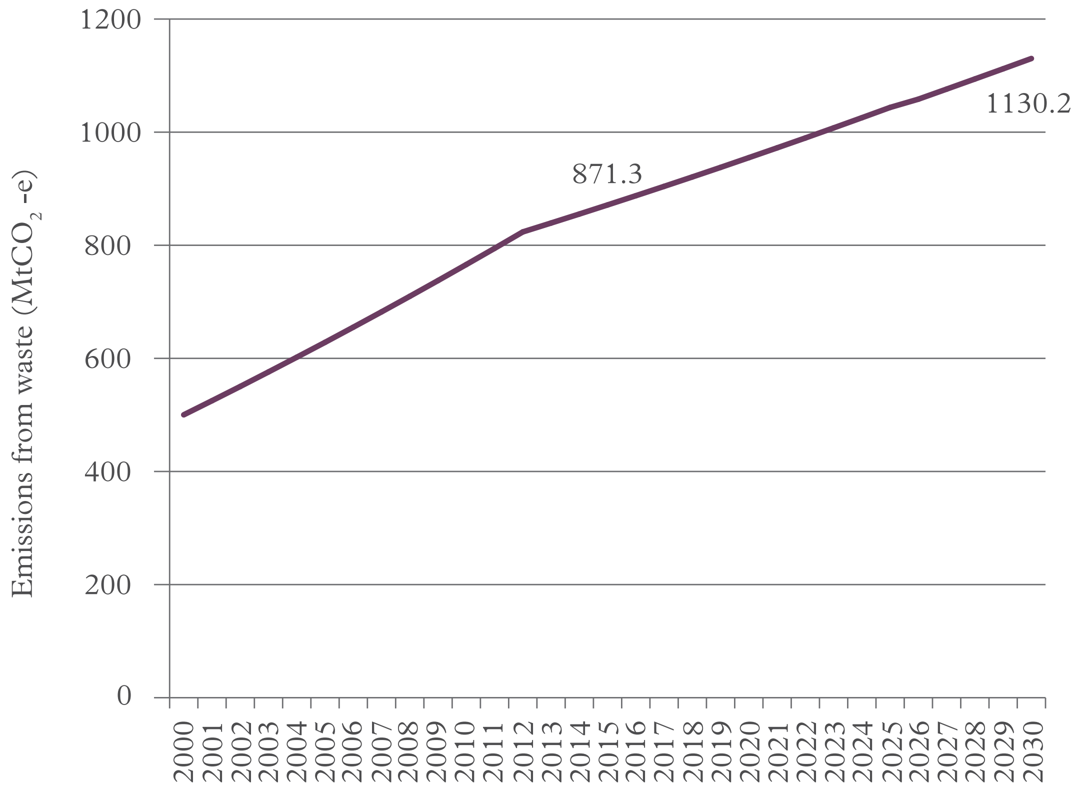
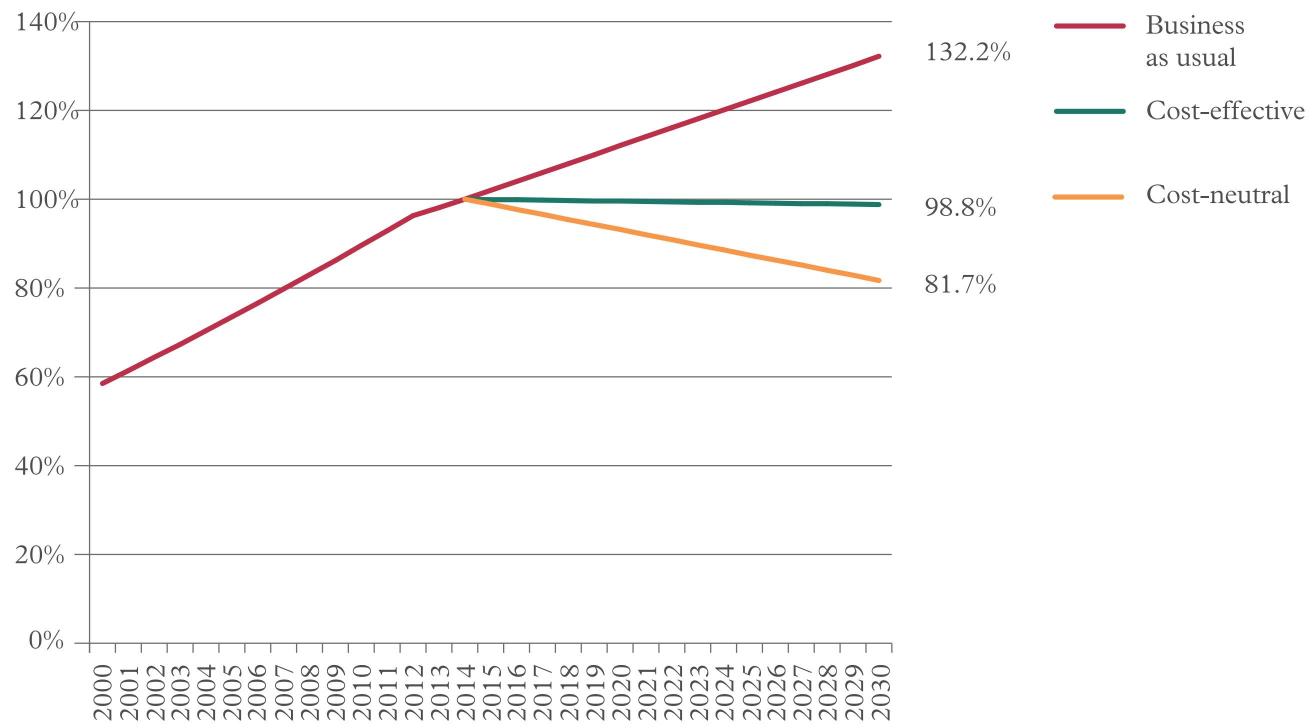



**Figure 17: Emissions from waste under three different investment scenarios, indexed to 2014 emissions, between 2000 and 2030.**



Cost effective

Cost neutral

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



**Table 9. League table of the cost-effectiveness of low carbon measures in the waste sector ($BRL/tCO_2$-e and $USD/tCO_2$-e).**

| Rank | Measure: | BRL $/tCO_2$-e | USD $/tCO_2$-e |
|---|---|---|---|
| 1 | Energy from waste (combined heat and power) | -202.78 | -86.32 |
| 2 | Hybrid waste collection retrofit | -151.26 | -64.39 |
| 3 | Energy from waste (electricity) | -134.70 | -57.34 |
| 4 | Landfill gas utilisation | -26.50 | -11.28 |
| 5 | Waste prevention - 10% of waste | 1.99 | 0.85 |
| 6 | Centralised composting | 2.81 | 1.20 |
| 7 | Waste prevention - 5% of waste | 3.82 | 1.63 |
| 8 | Landfill gas flaring | 16.75 | 7.13 |
| 9 | Recycling program - 40% | 23.91 | 10.18 |
| 10 | Home composting - 30% yield | 64.85 | 27.61 |
| 11 | Home composting - 15% yield | 68.30 | 29.08 |
| 12 | Recycling program - 20% | 79.65 | 33.91 |
| 13 | Incineration | 216.11 | 92.00 |

**Table 10. League table of the carbon-effectiveness of low carbon measures in the waste sector ($ktCO_2$-e).**

| Rank | Measure: | $ktCO_2$-e |
|---|---|---|
| 1 | Centralised composting | 7,878.44 |
| 2 | Landfill gas utilisation | 4,333.67 |
| 3 | Landfill gas flaring | 4,120.38 |
| 4 | Energy from waste (combined heat and power) | 3,661.55 |
| 5 | Incineration | 3,538.34 |
| 6 | Energy from waste (electricity) | 3,538.34 |
| 7 | Home composting – 30% yield | 2,541.35 |
| 8 | Recycling program - 40% | 2,438.34 |
| 9 | Home composting – 15% yield | 1,297.15 |
| 10 | Recycling program - 20% | 1,105.77 |
| 11 | Prevention – 10% | 1,133.51 |
| 12 | Prevention - 5% | 590.67 |
| 13 | Hybrid waste collection retrofit | 28.11 |

# Chapter 5.
# The Business Case for Low-Carbon Investment

### Introduction

Many of the energy efficiency, renewable energy and other low carbon measures identified in this study should be attractive to private sector actors under business as usual conditions. This document identifies flagship low carbon measures and presents the business case for wider dissemination. We consider the costs, returns and risks for the following low carbon investments:

1. Converting the existing bus fleet to hybrid vehicles by 2030
2. Implementation of European Union carbon emission vehicle standards
3. Landfill gas utilisation
4. 100% LED lighting by 2030 for commercial and public buildings
5. 20% improvement in the energy efficiency of air conditioners
6. 20MW of residential rooftop panels with an efficiency of ~17%

There is a direct, private economic case for these energy efficiency and renewable energy measures. These investments would also enhance the economic competitiveness, energy security and carbon intensity of Recife. These examples demonstrate that accounting for climate change in business planning can be attractive in commercial terms, above and beyond the immense benefits of reducing the future impacts of climate change.

### Converting the existing bus fleet to hybrid vehicles by 2030

This measure envisions that the existing bus fleet of Recife will be replaced with diesel-hybrid buses by 2030. Drawing on case studies of hybrid bus implementation in Brazilian cites and consultation with members of Recife's transport company, CBTU, hybrid buses are expected to operate at 40% higher efficiency than the average efficiency of the current bus fleet. Based on data on vehicle retirement rates, economic calculations assume that buses currently in the Recife fleet have an average life expectancy of 8 years. Although hybrid buses are expected to have 13% higher non-fuel operational costs and 77% higher capital costs they are also expected to have longer operational lifespans, conservatively estimated at 10 years.

This measure would avoid consumption of 74.60 million litres of fuel, reduce energy expenditure by BRL 283.89 million (USD 120.85 million) and reduce greenhouse gas emissions by 199.7 ktCO2-e. The economic case is presented in Table 11, assuming an annual increase of 2% in real energy prices and a real interest rate of 5%.

Key investment risks include:

1. Falling fuel prices would reduce the expected rate of return.
2. Declining ridership due to rising vehicle ownership would reduce the expected rate of return.
3. Higher operating costs or maintenance costs than are typical would reduce the expected rate of return.

**Table 11. The economic case for converting the bus fleet to hybrid vehicles in Recife.**

| Net present value (USD) | Capital investment (USD) | Energy savings in 2030 | Economic savings per year (USD) | Payback period (years) |
|---|---|---|---|---|
| 127.53 million | 609.10 million | 724.14 GWh | 71.34 million | 6.8 |



### European Union carbon emission vehicle standards

This measure envisions that national policymakers in Brazil implement European Union carbon emissions vehicle standards set out in EU Regulation No 443/2009. These regulations stipulate that light vehicle fleets produced by automakers emit, on average, 130gCO2/km from 2015 and of 95 CO2/km from 2021. For light commercial vehicles these regulations stipulate a standards of 175 CO2/km coming into effect in 2017 and a target of 147 CO2/km by 2020. Based on an analysis of the Pernambuco vehicle stock age distribution and growth rate, it was determined that 43.53% of the vehicle stock in Recife would be affected by these standards by 2030.

This measure would avoid consumption of 279.80 million litres of fuel, reduce energy expenditure by BRL 1.34 billion (USD 568.98 million) and reduce greenhouse gas emissions by 552.8 ktCO2-e. The economic case is presented in Table 12, assuming an annual increase of 2% in real energy prices and a real interest rate of 5%.

Key investment risks include:

1. Falling fuel prices would reduce the expected rate of return.
2. Negative impacts on domestic vehicle manufacturers if they cannot meet the carbon emission vehicle standards.
3. Rebound effects (increased consumption due to lower costs) result in higher vehicle mileage and emissions, outweighing the economic and carbon savings.
4. Compatibilities with ethanol standards.

**Table 12. The economic case for introducing EU carbon emission vehicle standards in Recife.**

| | Net present value (USD) | Capital investment (USD) | Energy savings per year | Economic savings per year (USD) | Payback period (years) |
|---|---|---|---|---|---|
| **Mid sized light duty vehicle** | 1987.15 | 4400.00 | 7136 KWh | 723.01 | 6.1 |
| **Across the vehicle fleet by 2030** | 1626.49 million | 709.22 million | 2420.20 GWh | 455.10 million | 3.2 |

### Landfill gas utilisation

This measure envisions the construction of landfill gas capture and electricity generation facilities at Jaboatão dos Guararapes municipal landfill. Considering the proportion of organic materials (approximately 55%), and the rate of waste production, it is assumed that 75% landfill gas collection could be achieved with an oxidation factor of 10% (due to landfill cover). Additionally, it is assumed that 10% of generated electricity is used on site. Based on these figures, Recife could generate 116.32 GWh of electricity per year in 2030.

This measure would generate 116.32 GWh of electricity, generate BRL 63.04 million (USD 26.84 million) of revenue and reduce greenhouse gas emissions by 324.6 ktCO2-e. The economic case is presented in Table 13, assuming an annual increase of 2% in real energy prices and a real interest rate of 5%.

Key investment risks include:

1. Falling electricity prices would reduce the expected rate of return.
2. Declining waste production from the city would reduce the expected rate of return.
3. Engineering challenges: a definitive engineering study will be required to determine the feasibility of investment.

**Table 13. The economic case for landfill gas utilisation in Recife.**

| Net present value (USD) | Capital investment (USD) | Economic savings per year (USD) | Payback period (years) |
|---|---|---|---|
| 88.08 million | 40.49 million | 148.14 million | 2.03 |



### 100% LED lighting by 2030 for commercial and public buildings

This measure envisions that all incandescent and compact fluorescent (CFL) lighting in commercial and public buildings will be replaced with light emitting diodes (LED) between 2015 and 2030. Assuming that the average CFL light bulb of 24W is replaced a LED bulb of 15W, this measure could reduce energy consumption from lighting by 37.5% in the public and commercial sector.

Due to the short lifespan of incandescent and CFL bulbs, this measure could be achieved within five years through the compulsory introduction of LED lighting. However, due to the relatively high capital cost of LED lights, we have assumed a replacement rate of 6.25% per year. While LED bulbs can cost up to seven times as much as their CFL counterparts, their lifespan is ten times longer (55,000 hours compared with 5,500 hours). Our calculations conservatively assume that the existing ban on incandescent light bubs has been effective and that LED bulbs would achieve 25% market penetration irrespective of policy interventions by 2030, based on falling production costs and improving luminosity.

This measure would avoid consumption of 148.37 GWh of electricity, reduce energy expenditure by BRL 23.60 million (USD 10.04 million) and reduce greenhouse gas emissions by 16.7 ktCO2-e. The economic case is presented in Table 14, assuming an annual increase of 2% in real energy prices and a real interest rate of 5%.

Key investment risks include:

1. Falling grid electricity prices would reduce the expected rate of return.
2. Split incentives between commercial building owners and tenants may make mobilsing the necessary investment difficult.
3. Higher capital costs can deter prospective investors.

**Table 14. The economic case for installing 100% LED lighting in commercial and public buildings in Recife.**

| | Net present value (USD) | Capital investment (USD) | Energy savings per year | Economic savings per year (USD) | Payback period (years) |
|---|---|---|---|---|---|
| **Individual unit** | 168.52 | 180.53 [1] | 32.85kWh | 32.80 [2] | 5.5 |
| **With 100% deployment by 2030** | 761.10 million | 815.37 million | 148.37 GWh | 148.14 million | 5.5 |

[1] LED units in a commercial building has an estimated cost of USD 274.03, while CFL units have an estimated cost of USD 93.50.
[2] Includes annualised costs of replacing CFL bulbs, which have a much shorter lifespan than LED bulbs.

### More efficient air conditioners

This measures envisions a 20% improvement in the average efficiency of air conditioners sold from the start of 2015. This could be achieved by banning Class D and E air conditioners under the existing PROCEL energy efficiency system (assuming equal market share among classes), or by banning Class E air conditioners and introducing endorsement labelling for Class A air conditioners.

This measure would avoid consumption of 148.37 GWh of electricity, reduce energy expenditure by BRL 23.60 million (USD 10.04 million) and reduce greenhouse gas emissions by 16.7 ktCO2-e. The economic case is presented in Table 15, assuming an annual increase of 2% in real energy prices and a real interest rate of 5%.

Key investment risks include:

1. Falling grid electricity prices would reduce the expected rate of return.
2. Split incentives between commercial building owners and tenants.
3. Rebound effects (increased consumption due to lower costs) outweighs the economic and carbon savings.

**Table 15. The economic case for more efficient air conditioners in Recife.**

#### Commercial and public sector

| | Net present value (USD) | Capital investment (USD) | Energy savings per year | Economic savings per year (USD) | Payback period (years) |
|---|---|---|---|---|---|
| **Individual unit** | 1,388.85 | 2,129 | 2.76 MWh | 329.15 | 6.5 |
| **With 100% deployment by 2030** | 205.34 million | 314.76 million | 408.0 GWh | 48.66 million | 6.5 |

#### Residential sector

| | Net present value (USD) | Capital investment (USD) | Energy savings per year | Economic savings per year (USD) | Payback period (years) |
|---|---|---|---|---|---|
| **Individual unit** | 305.18 | 128 | 248.4kWh | 34.27 | 3.7 |
| **With 100% deployment by 2030** | 102.16 million | 42.82 million | 83.1 GWh | 11.47 million | 3.7 |



### Rooftop solar PV panels

This measures envisions the installation of solar photovoltaic (PV) panels on 10% of residential buildings in Recife by 2030. This equates to approximately 3,400 households per year and a total of 54,400 households by 2030. We assume that each participating household would have a 3kW panel installed with an average efficiency of 17%. This would allow each household to generate approximately 4.5MWh. This is conservative: rapid improvements in technical efficiency of solar panels means that households joining the scheme at a later date could likely generate more electricity with comparable installed capacity.

This measure would generate 243.18 GWh of electricity, generate BRL 106.07 million (USD 45.2 million) of gross revenue and reduce greenhouse gas emissions by 27.4 ktCO2-e. The economic case is presented in Table 16, assuming an annual increase of 2% in real energy prices and a real interest rate of 5%.

Key investment risks include:

1. Extended periods of lower than expected energy production would reduce the expected rate of return.
2. Falling grid electricity prices would reduce the expected rate of return.
3. Extended operational failure may not be covered by normal maintenance warranties and contracts.
4. Increasing the level of intermittent electricity generation could create load-balancing challenges for the electricity grid.

**Table 16. The economic case for rooftop solar PV panels at the city-scale.**

| | Net present value (USD) | Capital investment (USD) | Energy generated per year | Economic savings per year (USD) | Payback period (years) |
|---|---|---|---|---|---|
| **Individual unit** | 15,975.74 | 9,093 | 4.5 MWh | 616.39 | 14.8 |
| **With deployment on 10% of residential buildings in 2030** | 209.06 million | 494.94 million | 243.2 GWh | 33.55 million | 14.8 |

# Chapter 6.
# Multi-criteria Analysis

## Introduction

While the presence of an economic and environmental case is an important condition for action, policy and investment decisions cannot be made on the basis of these criteria alone. The low carbon measures are ranked in Table 11 according to their weighted score across five criteria: political and public acceptability, capacities for their implementation, their contribution to human development and their wider impacts on the environment. The full results of the MCA are detailed in Appendix E.

It is apparent that investments in low carbon transport and domestic energy efficiency perform very well when we consider these broader social and sustainability aspects. All measures identified below perform very well in terms of political and public acceptability, although the preferred measures in the domestic sector are not perceived to contribute to development and climate goals as much as the transport investments.

**Table 17. The ten most attractive low carbon measures available to the city of Recife based on broad political, social and environmental criteria.**

| Rank | Measure | Political acceptability | Public acceptability | Capacities for implementation | Impact on human development | Impact on environment | Weighted score |
|---|---|---|---|---|---|---|---|
| 1 | Bike sharing | 3.9 | 4.2 | 4.1 | 4.7 | 4.7 | 4.17 |
| 2 | Investments to increase public transit use and safety | 4.0 | 4.3 | 3.9 | 4.8 | 4.4 | 4.14 |
| 3 | Air conditioner (EE Standard 1) | 4.5 | 4.5 | 4.5 | 2.9 | 3.0 | 4.11 |
| 4 | Air conditioner (EE Standard 2) | 4.5 | 4.5 | 4.5 | 2.9 | 3.0 | 4.11 |
| 5 | Refrigerator (EE Standard 1) | 4.3 | 4.3 | 4.5 | 2.9 | 2.9 | 3.98 |
| 6 | Refrigerator (EE Standard 2) | 4.3 | 4.3 | 4.5 | 2.9 | 2.9 | 3.98 |
| 7 | BRT - East West | 4.2 | 4.4 | 3.5 | 4.3 | 3.9 | 3.91 |
| 8 | BRT – North South | 4.2 | 4.4 | 3.5 | 4.3 | 3.9 | 3.91 |
| 9 | Bike lanes | 3.6 | 4.1 | 3.9 | 4.1 | 4.3 | 3.90 |
| 10 | Increase in bus service - 20% | 3.9 | 4.9 | 3.4 | 4.2 | 4.0 | 3.90 |

Cost effective

Cost neutral

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

**Table 18. The two most attractive low carbon measures in each sector of Recife based on broad political, social and environmental criteria.**

| Rank | Measure | Political acceptability | Public acceptability | Capacities for implementation | Impact on human development | Impact on environment | Weighted score |
|---|---|---|---|---|---|---|---|
| 1 | Bike sharing (2x current scheme) | 3.9 | 4.2 | 4.1 | 4.7 | 4.7 | 4.17 |
| 2 | Investments to increase public transit use and safety | 4.0 | 4.3 | 3.9 | 4.8 | 4.4 | 4.14 |
| 3 | Air conditioner – EE Standard 1 | 4.5 | 4.5 | 4.5 | 2.9 | 3.0 | 4.11 |
| 5 | Refrigerator – EE Standard 1 | 4.3 | 4.3 | 4.5 | 2.9 | 2.9 | 3.98 |
| 11 | LED street lighting | 4.1 | 4.7 | 3.0 | 3.9 | 4.4 | 3.89 |
| 17 | Waste prevention - 5% | 3.7 | 3.8 | 3.3 | 4.2 | 4.4 | 3.72 |
| 18 | Recycling program - 20% | 3.8 | 4.2 | 3.1 | 4.2 | 4.4 | 3.69 |
| 23 | Setting LED target of 100% by 2030 (commercial buildings) | 3.4 | 3.9 | 2.9 | 4.1 | 4.4 | 3.94 |

# Chapter 7. Discussion

## Introduction

Between 2000 and 2014, rapid economic growth in Recife (particularly of the services sector) led to relative decoupling between GDP, energy use and emissions in Recife. Indeed, the amount of energy and emissions required to generate a unit of GDP was reduced by a factor of three in each case. This relative decoupling enabled Recife to transition towards a more energy efficient and low carbon economy, indicating that substantial gains in human development can be achieved without a proportionate contribution to climate change.

However, looking forward to 2030, falling economic growth rates coupled with rising energy demand and almost constant carbon intensity of energy will see Recife regress towards more carbon-intensive development. Net emissions in Recife are projected to rise by 12.6% by 2020 and by 79.1% by 2030, relative to 2014 levels, under business as usual conditions.

Absolute levels of energy use are projected to rise at a rate of 4.8% per annum between 2014 and 2030. This will lead to an increase in energy bills of 7.2% per annum to BRL 6.50 billion (USD 2.77 billion) in 2030, and an increase of net emissions of 4.0% per annum to 3.01 MtCO2-e per year over the same period. The major increases in energy costs are associated with the transport sector where fuels are relatively expensive. The most significant growth in emissions also comes from the transport sector, as rising incomes drive a substantial expansion of vehicle ownership. These figures suggest that Recife's economic competitiveness and energy security would also be enhanced by climate mitigation options.

This study reveals a compelling economic case for large-scale investment in energy efficiency, renewable energy and other low carbon measures in Recife above and beyond these background trends. By 2030, the city can cut its emissions by 24.3% of projected emissions in the business as usual scenario through cost-effective investments that would pay for themselves on commercial terms in 5.6 years. If the profits from these investments are re-invested in low carbon measures, Recife can reduce their emissions 31.0% relative to business as usual trends and recover its investment in 11.0 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 economic development goals. Some of the most cost-effective options in commercial sector, such as high efficiency air conditioners, would increase the competitiveness of the local economy by reducing expenditure on energy. Economically attractive measures in the transport sector, including an expansion of bus networks and adoption of higher efficiency standards for vehicles, would enhance urban mobility, increase resilience to volatile energy prices and improve air quality. Cost-effective options in the residential sector, including passive cooling and mandatory energy performance standards, could ensure that households also capture the economic benefits of low carbon investment. 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 Recife.

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 where large-scale composting and recycling measures are not cost-effective, but yield substantial carbon savings. These measures offer opportunities for strategic domestic investments and international climate finance to achieve dramatic improvements in emissions intensity without crowding out private investment.

It is worth highlighting that Brazil has set a national target of reducing emissions by between 36.1% and 38.9% of emissions by 2020, relative to business as usual levels. Most of this is expected to come from improvements in forest governance. However, these results suggest that Recife could achieve comparable emissions reduction at no net cost to the city – albeit over the period 2015 to 2030. This underscores the untapped and substantial mitigation potential in Brazilian cities.

The rising energy intensity of GDP and per capita carbon emissions highlights that Recife is slowly shifting to a higher carbon development trajectory. This trend could be arrested through strategic investments in energy efficiency, mass transit, renewable energy and other low carbon measures. The compelling economic case for low carbon investment, coupled with growing public engagement with environmental issues, provide a strategic opportunity to integrate climate considerations into urban planning.



## Conclusions and Recommendations

Business as usual trends in Recife will lead to a steady increase in the energy intensity of economic activity in the city. At the same time, absolute levels of energy use and emissions are continuing to rise steadily due to the effects of population and economic growth. Energy bills are also increasing steadily, which will have significant implications for economic competitiveness and social equity.

This research reveals that there are many economically attractive opportunities to increase energy efficiency and stimulate renewable energy investment, which would in turn improve the economic competitiveness, energy security and carbon intensity of Recife. The scale of the opportunities demonstrates that accounting for climate change in urban planning 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 composition of these opportunities, this report will help to build political commitment and institutional capacities for change. We also hope this report will help Recife to secure the investments and develop the delivery models needed to pursue climate action. Some of the energy efficiency and low carbon opportunities could be commercially attractive whilst others may only be viable with international climate finance. Many of the opportunities would benefit from the support of enabling policies from government.

We stress that economic considerations should not shape the transition to a low carbon development model in urban Brazil. Decision-makers should also consider issues relating to the equity, inclusivity and broader sustainability of the different options, as outlined in our multi-criteria appraisal. However, we understand that the presence of a compelling economic case is often necessary for decision-makers to consider the broader case for investment. We therefore hope that this evidence base on the opportunities for low carbon investment in Recife helps to mobilise political will for and public interest in ambitious climate action in Recife.

# References


Bitoun J, Miranda L, de Almeida Souza MA, de Britto Lyra MR. 2010. Região Metropolitana do Recife no Contexto de Pernambuco no Censo 2010. Observatório Das Metrópoles. Available from <http://www.observatoriodasmetropoles.net/download/Texto_BOLETIM_RECIFE_FINAL.pdf> [viewed 18/08/2014]

Conselho de Arquitetura e Urbanismo de Pernambuco. 2012. Elementos para um projecto de cidade e do território. Available from <http://www.clickn.com.br/public/CAU_PE_Prefeitos_DocCompletoR01aVersaoImpressao.pdf> [viewed 02/02/2015]

Costa MBSF, Mallman DLB, Pontes PM, Araujo M. 2010. Vulnerability and impacts related to the rising sea level in the Metropolitan Center of Recife, Northeast Brazil. Pan-American Journal of Aquatic Sciences 5(2) 341-349.

Da Letra T. 2013. Trânsito e transporte são os maiores problemas do Recife. Available from <http://www.diariodepernambuco.com.br/app/noticia/vida-urbana/2013/10/16/interna_vidaurbana,468322/transito-e-transporte-sao-os-maiores-problemas-do-recife.shtml> [viewed 18/08/2014]

EIA. 2014. Brazil. Energy Information Agency. Available from <http://www.eia.gov/countries/cab.cfm?fips=br> [viewed 18/08/2014]

EPE. 2012 Informa à Imprensa: demanda de energia eléctrica – 10 anos. Empresa de Pesquisa Energética. Available from <http://www.epe.gov.br/imprensa/PressReleases/20120104_3.pdf> [viewed 18/08/2014]

EY. 2011. Sustainable Brazil: Economic Growth and Consumption Potential. Ernst & Young Terco. Available from <http://www.ey.com/Publication/vwLUAssets/Sustainable-Brazil_Economic-growth-and-consumption-potential/$FILE/Sustainable-Brazil_Economic-growth-and-consumption-potential.pdf > [viewed 18/08/2014]

Ghisi E, Gosch S, Lamberts R. 2007. Electricity end-uses in the residential sector of Brazil. Energy Policy. 35(8) 4107-4120

Gouldson A, Colenbrander S, Sudmant A, Papargyropoulou E. 2014. The Economics of Low Carbon Cities: Palembang, Indonesia. The Centre for Low Carbon Futures. Available from <http://www.climatesmartcities.org/sites/default/files/4336%20Indonesia%20Report%20v5.pdf> [viewed 19/08/2014]

Gouldson A, Kerr N, Topi C, Dawkins E, Kuylenstierna J, Pierce R. 2012. The Economics of Low Carbon Cities: A Mini-Stern Review for the Leeds City Region. The Centre for Low Carbon Futures. Available from <http://www.climatesmartcities.org/sites/default/files/Mini-Stern%20Review_0.pdf> [viewed 19/08/2014]

IBGE. 2014. Brazil GDP Annual Growth Rate, 1991-2014. Instituto Brasileiro de Geografia e Estatística. Available from <http://www.tradingeconomics.com/brazil/gdp-growth-annual> [viewed 18/08/2014]

ICLEI. 2014. Inventário de Emissões de Gases de Efeito Estufa do Recife. Local Governments for Sustainability (ICLEI), Urban Low Emission Development Strategies (UrbanLEDS) and the City of Recife.

IPEA. 2014. IPEAdata. Instituto de Pesquisa Econômica Aplicada (Institute for Applied Economic Research). Available from <http://www.ipeadata.gov.br/> [viewed 18/08/2014]

MCTI, SEPED, CGMC. 2013. Estimativas anuais de emissões de gases de efeito estufa no Brasil. Ministério da Ciência, Tecnologia e Inovação, Secretaria de Políticas e Programas de Pesquisa e Desenvolvimento, Coordenação Geral de Mudanças Globais de Clima. Available from <http://www.ghgprotocol.org/files/ghgp/event%20sheet.pdf> [viewed 18/08/2014]

Ministério do Meoi Ambiente. 2014. Política Nacional sobre Mudança do Clima. Available from <http://www.mma.gov.br/clima/politica-nacional-sobre-mudanca-do-clima> [viewed 18/08/2014]

Secretaria de Desenvolvimento e Planejamento Urbano. 2010. O Recife: Informações socioeconômicas. Secretaria de Desenvolvimento e Planejamento Urbano (Department of Urban Planning and Development). Available from <http://www2.recife.pe.gov.br/o-recife/informacoes-socioeconomicas/> [viewed 18/08/2014]

TSP. 2010. The Top 20 GHG Emitting Countries – Breakdown by Sector. The Shift Project Data Portal. Available from <http://www.tsp-data-portal.org/TOP-20-emitter-by-sector#tspQvChart> [viewed 18/08/2014]

UNEP. 2012. Global Initiative for Resource Efficient Cities. United Nations Environmental Programme.

UNFCCC. 2007. Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries. United Nations Framework Convention on Climate Change. Available from <http://unfccc.int/resource/docs/publications/impacts.pdf> [viewed 18/08/2014]

World Bank. 2011. Recife Education and Public Management Project. Washington, DC. Available from <www-wds.worldbank.org/.../646760PID0BR0Recife0education.docx> [viewed 18/08/2014]

World Bank. 2014. Brazil. Washington, DC. Available from <http://data.worldbank.org/country/brazil> [viewed 18/08/2014]

World Bank and PPIAF. 2006. Urban Bus Toolkit: Recife. Washington, DC. Available from <http://www.ppiaf.org/sites/ppiaf.org/files/documents/toolkits/UrbanBusToolkit/assets/CaseStudies/summy/sum_recife.html > [viewed 20/08/2014]




# Appendices

## Appendix A:

## Workshop Participants

| Institution | Participants |
|---|---|
| ACI-Environmental Solution | Aloysio Costa Junior |
| Ameciclo | Daniel Valença |
| AMUPE | Etienete Braga Romaguera |
| APAC | Maria Aparecida Fernandes |
| Arte e Cultura Consultoria | Fabiana Pasini Lira |
| Attitude Center | Lígia Maria Pereira Lima<br>Jáson Torres |
| Câmara Recife | Eurico Freitas |
| CELPE | Thiago Dias Caires<br>Mariana Lorena |
| CELPE-EIMA | Carmen Carneiro |
| COMPESA-GMA | Neemias de Oliveira Gueiros |
| CONAMA | Oseas Omena |
| Concremat | Giullian Rodrigues |
| Consulado Britânico | Graham Tides |
| CPRH | Ildeane Machado<br>Andre Santidade |
| CREA | Alberto Lopes |
| CTTU | Fernanda Abola<br>Sandra Barbosa<br>André Luis Pereira |
| EMLURB | Bárbara Arrais<br>Élidas Dias<br>Laura Pereira |
| FAFIRE | Dinabel Vilas-Boas |
| FIEPE | Abraão Rodrigues |
| Gabinete do Vereador Eurico Freire | Marina Costa |
| GAMA | Sandra Guedes |
| Grande Recife | Cristiane Figueiredo<br>Cícero R. S. Monteiro |
| Hemobras | Gleidce Tamires Alves de Olivera |
| ICLEI | Eduardo Baltar<br>Jussara Carvalho<br>Igor Reis de Albuquerque<br>Gustavo Pereira |
| IFPE | Marialva Mello Fabisais |
| INCITI — Parque Capibaribe | Savio Machado |
| IPS / Municipality of Recife | Fernando de Alcantara |

| Institution | Participants |
| --- | --- |
| **ISOCARP** | Andries Geerse<br>Bertrand Sampaio de Alencar |
| **ITEP** | Wanderson Santos |
| **Lafaerte Locations** | Rogério M. Cruz |
| **Master Plan** | Mauro Buarque |
| **Municipality of Recife** | Robson Canuto da Silva |
| **Nordeste Clima** | José Carlos Lima |
| **Parque Capibaribe** | Rafaella Cavalcanti |
| **ProRural** | Alexandre Ramos |
| **Reserva Camará** | Felipe O. C. Coelho |
| **SAJ** | Eugênia Simões |
| **SANEAR** | Erika Oliveira<br>Mariane Regis |
| **SDEC/Municipality of Recife** | Rita de Cássia Figueiredo |
| **SDPU/Municipality of Recife** | Tiago Henrique de Oliveira |
| **SEDEC/Municipality of Recife** | Patrícia Renata de Albuquerque<br>Keila Ferreira |
| **SEHAB/Municipality of Recife** | Renata Lucena Borges<br>Danillo Franciso Tenório |
| **SEMAS** | Cristiano Carrilho<br>Walber Santana |
| **SEMOC/Muncipality of Recife** | José Fernandes |
| **SEPLAG/Municipality of Recife** | Alexandra G. Braga<br>Taciana Sotto-Mayor |
| **Sinduscon** | Julia Malheiros |
| **SMAS/Municipality of Recife** | Gustavo André C. Barbosa<br>Mauricéia Araújo<br>Marcelo Bentas<br>Maurício J. Bezerra<br>Walter Blossey<br>Maria da Glória de S. Brandão<br>Cristina Caldas<br>Alessandra de Carvalho<br>Israel Cassemino<br>Talyta dos Santos Guedes<br>Luiz Roberto de Oliveira<br>Maurício Guerra<br>Antonio Machado |





| Institution | Participants |
| --- | --- |
| **SMAS/Municipality of Recife** *continued* | Inamara Melo<br>Cida Pedrosa<br>Walkíria Prado<br>Nilo Rocha<br>Thaís Borges Romeno<br>Clarisse Wanderley |
| **UAG/UFRPE** | Werônica Meira de Souza |
| **UFPE** | Ruskin Freitas<br>Suzana Montenegro |
| **UFRPE e IFPE** | Hernande Pereira da Silva |
| **UNICAMP** | Silvia Stuchi Cruz<br>Roberto Spinelli |
| **URB** | Norah Neves |
| **USP** | Lucas Ciola<br>Antonio Fucá |

## Data Sources, Methods and Assumptions

| Activity | Projection method | Useful data |
|---|---|---|
| **Electricity generation and emissions factor estimates** | Electricity generation and emissions factor data were obtained from the Brazilian Ministry of Science and Technology (MCTI, 2014) and the UK Department for Environment, Food & Rural Affairs (DEFRA, 2009). Projections through to 2030 were informed by World Bank estimates of changes in generation capacity in Brazil through 2030 (Yepez-García *et al.*, 2010; Tolmasquim, 2012). | The carbon intensity of electricity in Recife is estimated to be:<br><br>– 2014: 0.098 $tCO_2$-e/MWh<br>– 2030: 0.113 $tCO_2$-e/MWh |
| **Energy prices** | Nominal energy prices in Brazil between 2000 and 2012 were obtained from Ministério de Minas e Energia and Empresa de Pesquisa Energética (EPE, 2009, 2014). Where necessary, these were converted to USD using the average annual midpoint exchange rate provided by OANDA for each year (OANDA, 2014). Nominal prices were converted into real prices with 2013 as the base year using the World Bank Consumer Price Index (World Bank, 2014). | The real electricity price in USD per MWh in 2014 for each tariff is:<br><br>– residential: 260.7<br>– public lighting: 103.7<br>– RCH bodies and agencies:184.0<br>– commercial: 176.0<br>– public power: 191.2<br>– public service: 125.8<br>– industrial: 186.7<br><br>The real price in USD in 2014 for other energy sources is:<br><br>– LPG: 1,709/ton<br>– natural gas: 690.6/thou $m^3$<br>– fuel oil: 580.1/ton<br>– gasoline: 1,546.9/$m^3$<br>– diesel: 1,180.1/$m^3$<br>– ethanol: 1,098.3$m^3$<br>– biodiesel: 1,215.5$m^3$ |
| **Commercial sector** | Data on energy consumption by fuel type in Recife in 2012 were obtained from ICLEI (2014). Data on changing rates of electricity consumption between 2006 and 2012 within Pernambuco were obtained from Ministério de Minas e Energia (EPE, 2011, 2013). Data on changing consumption rates of LPG, natural gas and oil at a national scale between 2000 and 2012 were obtained from Ministério de Minas e Energia and Empresa de Pesquisa Energética (EPE, 2009, 2014). | Commercial electricity consumption in 2014 was 1.80TWh, divided among the public lighting (5.5%), traffic signs (<0.1%), RCH bodies and agencies (1.6%), commercial (71.6%), public power (16.0%) and public service (5.3%) tariffs. In the same year, the sector also consumed 5,472 tons of LPG and 490.3$m^3$ of natural gas. |
| **Residential sector** | Data on energy consumption by fuel type in Recife in 2012 were obtained from ICLEI (2014). Data on changing rates of electricity consumption between 2006 and | In 2014, the residential sector in Recife consumed 1.31TWh of electricity, 43,060 tons of LPG and 3,041$m^3$ of natural gas. |





| Activity | Projection method | Useful data |
|---|---|---|
| **Residential sector** *continued* | 2012 in Pernambuco were obtained from Ministério de Minas e Energia (EPE, 2011, 2013). Data on changing consumption rates of LPG and natural gas at a national scale between 2000 and 2012 were obtained from Ministério de Minas e Energia and Empresa de Pesquisa Energética (EPE, 2009, 2014). | |
| **Industrial sector** | Data on energy consumption by fuel type in Recife in 2012 were obtained from ICLEI (2014). Data on changing rates of electricity consumption between 2006 and 2012 in Pernambuco were obtained from Ministério de Minas e Energia (EPE, 2011, 2013). Data on changing consumption rates of LPG, oil and natural gas at a national scale between 2000 and 2012 were obtained from Ministério de Minas e Energia and Empresa de Pesquisa Energética (EPE, 2009, 2014). | In 2014, the industrial sector in Recife consumed 237.34GWh of electricity, 4151.6 tons of LPG, 63.7 million $m^3$ of natural gas and 861.1$m^3$ of oil. |
| **Transport sector** | Data on energy consumption by fuel type in Recife in 2012 were obtained from ICLEI (2014). Data on changing consumption rates of gasoline, diesel, ethanol, vehicular natural gas and biodiesel at a national scale between 2000 and 2012 were obtained from Ministério de Minas e Energia and Empresa de Pesquisa Energética (EPE, 2009, 2014). | In 2014, the transport sector in Recife consumed 3.91TWh of gasoline, 2.2TWh of diesel, 493.4GWh of ethanol and 212.3GWh of vehicular natural gas. |
| **Waste sector** | Data on waste generation, waste composition and recycling rates in 2012 were provided by the Recife Urban Cleaning and Maintenance Unit (EMLURB) and ICLEI (2014). Projections of changes in waste production and composition are based on World Bank estimates (Hornweg and Bhada-Tata, 2012). 2006 IPCC Guidelines for National Greenhouse Gas Inventories and the GHG Protocol for Community Scale GHG Emissions formed the basis of the calculation of greenhouse gas emissions (IPCC, 2006; Connor et al., 2012). | In 2014, Recife generated 826,840 tonnes of waste.<br><br>Waste composition:<br><br>– Household: 68.4%<br>– Bulk waste (industry, commercial and construction): 29.9%<br>– Organic city maintenance waste: 1.4%<br>– Healthcare: 0.1% |
| **Exchange rate** | Exchange rates were based on the midpoint annual averages for 2000 – 2014 from OANDA (2015). The 2014 exchange rate was used for all projections. | 2014 exchange rates:<br>BRL/USD: 0.4257<br>USD/BRL: 2.3475 |

## References for Appendix B


Connor J, Feldon A, Eichel A, Russell B, Dickinson J, Hoornweg D, Bhatia P, Fong WK, Shearer I. 2012. Global Protocol for Community-Scale GHG Emissions (GPC) Version 0.9 – 20 March 2012. Available from <http://www.ghgprotocol.org/files/ghgp/GPC%20v9%2020120320.pdf> [viewed 30/08/2014]

DEFRA. 2009. "Annex 10 - International Electricity Emission Factors", in 2009 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting. Department for Environment, Food and Rural Affairs. Available from <http://archive.defra.gov.uk/environment/business/reporting/pdf/20090928-guidelines-ghg-conversion-factors.pdf> [viewed 12/08/2014]

EPE. 2009. Balanço Energético Nacional 2008. Ministério de Minas e Energia, Empresa de Pesquisa Energética. Available from <https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2009.pdf> [viewed 12/08/2014]

EPE. 2011. Anuário estatístico de energia elétrica 2011. Ministério de Minas e Energia, Available from <http://www.epe.gov.br/AnuarioEstatisticodeEnergiaEletrica/20111213_1.pdf> [viewed 12/08/2014]

EPE. 2014. Balanço Energético Nacional 2013. Ministério de Minas e Energia, Empresa de Pesquisa Energética. Available from <https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2014.pdf> [viewed 12/08/2014]

EPE. 2013. Anuário estatístico de energia elétrica 2013. Ministério de Minas e Energia. Available from <http://www.epe.gov.br/AnuarioEstatisticodeEnergiaEletrica/20130909_1.pdf> [viewed 12/08/2014]

Hoornweg D, Bhada-Tata P. 2012. What a waste: A global review of solid waste management. World Bank. Washington, DC. Available from <https://openknowledge.worldbank.org/handle/10986/17388> [viewed 19/08/2014]

ICLEI. 2014. Inventário de Emissões de Gases de Efeito Estufa do Recife. Local Governments for Sustainability (ICLEI), Urban Low Emission Development Strategies (UrbanLEDS) and the City of Recife.

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Volume 5: Waste. Available from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf> [viewed 30/08/2014]

MCTI. 2014. Arquivos dos Fatores de Emissão. Ministério da Ciência e Tecnologia. Available from <http://www.mct.gov.br/index.php/content/view/321144.html#ancora> [viewed 12/08/2014]

OANDA. 2015. Historical exchange rates. Available from <http://www.oanda.com/currency/historical-rates/> [viewed 08/01/2015]

Tolmasquim MT. 2012. The energy sector in Brazil: policy and perspectives. Estudos Avançados. 26 (74) 249-260

World Bank. 2014. Consumer price index (2010 = 100). Available from <http://data.worldbank.org/indicator/FP.CPI.TOTL> [viewed 14/08/2104]

Yepez-García R, Johnson MT, Andrés LA. 2010. Meeting the electricity supply/demand balance in Latin America & the Caribbean. The World Bank. Washington, DC.




## Appendix C:

## Data Sources, Methods and Assumptions

### The Commercial and Public Sector

| Measure | Summary and key assumptions |
| --- | --- |
| **Energy efficient air conditioners** | Air conditioners are responsible for about 70% of energy consumption by commercial buildings in Brazil (Carvalho *et al.*, 2010). This proportion is assumed to be constant in the business as usual scenario to 2030. We calculated average efficiency and energy use at a building level by reverse engineering from data about number of commercial buildings (figures provided by the Recife Department of Development and Urban Planning) and total energy use between 2000-2010, and then forecast this to 2030 to determine BAU energy consumption for individual air conditioners.<br><br>Two mandatory energy performance standards are modelled:<br><br>— EE Standard 1. Savings calculated here consist of 10% of business-as-usual energy consumption for new air conditioners. This has approximately the same impact as introducing endorsement labelling for Class A air conditioners or of banning Class E air conditioners under the existing PROCEL system, assuming equal market share among classes and using the minimum coefficients of performance for each class from Cardosa *et al.* (2012).<br>— EE Standard 2. Savings consist of 20% of business-as-usual energy consumption for new air conditioners. This has approximately the same impacts as banning Class D and E air conditioners under the existing PROCEL system, assuming equal market share among classes and using the minimum coefficients of performance for each class from Cardosa *et al.* (2012).<br><br>Energy savings are calculated over a fifteen year lifetime, with a consequent retirement rate of 6.7% per year. Observed prices online and in outlet stores in Sao Paolo suggested that price differentials among air conditioners are not based on energy efficiency ratings. An tadditional cost of BRL2,000 per building was assumed with EE1 standards for air conditioners and of BRL5,000 per building with EE2 standards for air conditioners. This is conservative, since highly efficient options were available at no significant additional cost. |
| **Energy efficient elevators and escalators** | Escalators and elevators typically account for 3-8% of a commercial buildings' electricity consumption (e4 project, 2010). We have therefore assumed 5.5% of electricity sold under the commercial and public service tariffs in Recife is used to power escalators and elevators. We model two standards of energy efficiency for elevators and escalators in new buildings:<br><br>– EE Standard 1. Savings consist of 20% business-as-usual energy consumption.<br>– EE Standard 2. Savings consist of 40% of business-as-usual energy consumption.<br><br>These figures are based on data from De Almeida *et al.* (2012) which suggest that technical efficiency potentials of more than 60% exist for elevators and around 30% for escalators. We assume no difference in capital cost for more efficient models, using data from the e4 Project (2010). |

## The Commercial and Public Sector

*continued*

| Measure | Summary and key assumptions |
|---|---|
| **Green building standards** | There are a wide range of options available to reduce energy consumption by this much including (but not limited to) building orientation, building form, height-to-floor-area ratio, window-to-wall area ratios, insulation levels, window properties, use of thermal mass within buildings and passive ventilation/cooling.<br><br>We model two levels of energy savings:<br>— Green Building Standard 1: savings consist of 10% of energy consumed by air conditioners.<br>— Green Building Standard 2: savings consist of 20% of energy consumed by air conditioners.<br><br>Many energy efficiency options would have no additional cost if integrated at the design and construction stages, but to be conservative, we have assumed an additional cost of USD2/$m^2$ to meet Green Building Standard 1, and USD5/$m^2$ to achieve Green Building Standard 2.<br><br>Air conditioners are assumed to account for 70% of electricity consumption by commercial buildings in Brazil under business-as-usual conditions (Carvalho *et al.*, 2010). The share of energy consumption by air conditioners in the commercial sector has been growing steadily from around 20% in the late 1990s, although even then air conditioners already accounted for over half of consumption in large office buildings, shopping centres and hotels (Geller *et al.*, 1998). Energy savings are calculated to 2040. |
| **LED street lighting** | Total savings of 58% from full deployment of LED lights are estimated. This was the average from a trial of 12 cities, with a range of 50-70% (The Climate Group, 2012). Drawing on data from the US Office of Energy Efficiency and Renewable Energy, the cost of an LED street light was assumed to be USD274.03 compared with USD97.50 for a standard bulb (Department of Energy, 2014). |
| **Retrofit with double glazing plus insulation** | Double glazing with reflective windows and polystyrene insulation in commercial buildings cuts 4.95% of electricity consumption by air conditioners and 3.31% of total electricity consumption, based on a Brazilian case study (Carvalho *et al.*, 2010). Four scenarios are modelled:<br><br>— Retrofitting 10% of existing commercial buildings;<br>— Retrofitting 20% of existing commercial buildings;<br>— Retrofitting 50% of existing public buildings; and<br>— Retrofitting 100% of existing public buildings.<br><br>In both scenarios, the retrofit program is delivered over three years (2015-2017). Costs were calculated from a value of CAD140/m2 (Harvey, 2009), with a total commercial and public building floor space of 15,445,915$m^2$ in Recife. This figure was provided by staff in the Department of Development and Urban Planning for the city. |



| Measure | Summary and key assumptions |
|---|---|
| **Setting LED targets for indoor lighting** | Savings consist of saved energy if a target of 100% LED lighting is effectively realised in commercial and public buildings by 2030. The model assumes the existing ban on incandescent light bubs has been effective (a conservative assumption since up to 50% of Brazilian households still had incandescent bulbs in their house in 2013, according to Vahl *et al.* (2013)) and that LED bulbs would achieve 25% market penetration irrespective of policy interventions by 2030, based on falling production costs and improving luminosity. Energy consumption by lighting from 2015-2030 is assumed to be 20% of BAU consumption by commercial and public buildings, a conservative estimate based on US levels of 21.7% (Department of Energy, 2011). The average CFL light bulb is assumed to be 24W, being replaced a LED bulb of 15W. An LED light bulb in 2014 has a cost of BRL130 and a lifespan of 50,000 hours; a CFL light bulb in 2014 has a cost of BRL18 and a lifespan of 5,500 hours (Vahl *et al.*, 2013). |
| **Solar PV panel: a-Si** (amorphous silicon) | 20kW rooftop solar PV panel modelled. Average conversion efficiency of 6.3%. Average generation of 140MWh per panel. Electricity feeds into the public grid 30% of the time (Ordenesa et al., 2007). Two scenarios are modelled:<br><br>— Target of additional 10MW installed capacity by 2030.<br>— Target of additional 20MW installed capacity by 2030.<br><br>The price of a 20kWp a-Si solar PV panel in the commercial sector is based on the minimum technology costs in EPE (2012) (due to the low conversion efficiency of the technology), plus 20% installation, fee and import tax costs. No feed-in tariff is considered because the cost per MWh of rooftop solar is already below retail electricity prices (FS-UNEP and BNEF, 2014). |
| **Solar PV panel: HIT** (heterojunction comprised of a thin a-Si PV cell on top of a c-Si cell) | 20kW rooftop solar PV panel modelled. Average conversion efficiency of 17%. Average generation of 256.5MWh per solar panel. Electricity feeds into the public grid 30% of the time (Ordenesa et al., 2007). Two scenarios are modelled:<br><br>— Target of additional 10MW installed capacity by 2030.<br>— Target of additional 20MW installed capacity by 2030.<br><br>The price of a 20kW HIT solar PV panel in the commercial sector is assumed to be proportionate to the price of a 3kW HIT solar PV panel in ABINEE (2012) (i.e. the same cost multiplied by 20/3), which does not specify the technology but has a comparable conversion efficiency. No feed-in tariff is considered because the cost per MWh of rooftop solar is already below retail electricity prices (FS-UNEP and BNEF, 2014). |
| **Turning off indoor lights** | Savings consist of the energy used for one hour of lighting per day. The average light bulb in the commercial and public sector is used for an estimated ten hours per day. |

| Measure | Summary and key assumptions |
|---|---|
| **Energy efficient air conditioners** | Data on ownership and use of air conditioners in Brazil between 1998 and 2005 were collected from Electrobras (1998) and McNeil and Letschert (2010), along with a projected level of air conditioner ownership in 2030. Two competing trends are at play. While Brazilian air conditioners are showing improved energy efficiency – the average energy efficiency rating (EER) in 2005 was 2.84 out of 5, but this is expected to rise to 3.2 out of 5 by 2010 (McNeil MA, Letschert, VE. 2008) – use of air conditioners is increasing with income. We reverse engineered the average efficiency of household air conditioners in 1997 and 2010 based on data about number of households (figures provided by the Recife Department of Development and Urban Planning) and the data on levels of ownership and use, and then forecast this to 2030 to determine BAU energy consumption.<br><br>Two mandatory energy performance standards are modelled:<br><br>— EE Standard 1. Savings calculated here consist of 10%, 20% and 30% of business-as-usual energy consumption in 2015, 2020 and 2025 respectively. This has approximately the same impact as introducing endorsement labelling for Class A air conditioners or of banning Class E air conditioners under the existing PROCEL system, assuming equal market share among classes and using the minimum coefficients of performance for each class from Cardosa *et al.* (2012).<br>— EE Standard 2. Savings consist of 20%, 40% and 60% of business-as-usual energy consumption in 2015, 2020 and 2025 respectively. This has approximately the same impacts as banning Class D and E air conditioners under the existing PROCEL system, assuming equal market share among classes and using the minimum coefficients of performance for each class from Cardosa *et al.* (2012).<br><br>Energy savings are calculated over a fifteen year lifetime, with a consequent retirement rate of 6.7% per year. Observed prices online and in outlet stores in Sao Paolo suggested that price differentials among air conditioners are not based significantly on energy efficiency ratings. In the absence of standard price differences and with an observed price range of BRL1,000-1,500 for a 2.6kW model, an additional cost of BRL150 was assumed with EE1 standards and of BRL300 with EE2 standards. This is conservative, since highly efficient options were available at no significant additional cost. |
| **Energy efficient refrigerators** | Data for ownership of refrigerators in Northeast Brazil between 2000 and 2007 were collected from Achão and Schaeffer (2009). Growth rates to 2030 were projected using a forecast function, which produced an average growth rate of 0.7%. PARC energy efficiency for refrigerators in Northeast Brazil for 2010 is based on data from Cardoso et al. (2010), assuming equal market share among the five classes (A-E) of energy efficiency and an average size of 250L per refrigerator is assumed. Background energy efficiency improvements of 1.9% are assumed, based on those provided for 1990-2005 in Cardoso et al. (2010) and excluding those years where MEPS were introduced.<br><br>Brazil has already established mandatory energy performance standards (MEPS) for refrigerators. These consist of abolishing the lowest efficiency classes (F and G), mandatory labelling of energy consumption and endorsing highly efficient appliances. |



| Measure | Summary and key assumptions |
|---|---|
| **Energy efficient refrigerators** *continued* | Two additional MEPs are modelled:<br><br>— EE Standard 1. Savings calculated here consist of 10%, 20% and 30% of business-as-usual energy consumption in 2015, 2020 and 2025 respectively. Based on the energy consumption of different classes of refrigerators in Cardoso et al. (2010), this is approximately equivalent to banning the sale of Class E refrigerators as categorised the current PROCEL system.<br>— EE Standard 2. Savings consist of 20%, 40% and 60% of business-as-usual energy consumption in 2015, 2020 and 2025 respectively. Based on the energy consumption of different classes of refrigerators in Cardoso et al. (2010), this is approximately equivalent to banning the sale of Class D and E refrigerators as categorised the current PROCEL system.<br><br>These savings are conservative compared with the technical potential calculated by de Melo and de Martino Jannuzzi (2010). Energy savings are calculated over a fifteen year lifetime. |
| **Energy efficient televisions** | Data for ownership of televisions in Northeast Brazil between 2000 and 2007 were collected from Achão and Schaeffer (2009). The growth rate of sales to 2030 was based on a macroeconomic model produced by Park (2011). Data on average energy consumption by televisions in Brazil in 2012 and 2015 were obtained from Park (2011). These figures reveal a slight decrease in per unit consumption, which Park attributes due to a large-scale technological transition from CRT to LCD and CCFL-LCD to LED-LCD. However, in the longer term, efficiency gains are likely to be offset by increasing screen size so BAU per unit energy consumption has been held constant at 2015 levels.<br><br>Two MEPS are modelled:<br>1. EE Standard 1. Savings calculated here consist of 10%, 20% and 30% of business-as-usual energy consumption in 2015, 2020 and 2025 respectively.<br>2. EE Standard 2. Savings consist of 20%, 40% and 60% of business-as-usual energy consumption in 2015, 2020 and 2025 respectively.<br><br>These savings are conservative based on the technical potential at no net cost with current LED-LCD televisions, which are expected to make up 80% of Brazilian new purchases by 2015 (Park et al., 2013). Energy savings are calculated over a ten year lifetime. |
| **Energy efficient washing machines** | Data for ownership of washing machines in Northeast Brazil between 2000 and 2007 were collected from Achão and Schaeffer (2009). Growth rates to 2030 were projected using a forecast function, which produced average growth rates of 1.5%.<br><br>Two MEPS are modelled:<br>— EE Standard 1. Savings calculated here consist of 5%, 10% and 15% of business-as-usual energy consumption in 2015, 2020 and 2025 respectively. Based on the energy consumption of different classes of washing machines in ISIS (2007), this is approximately equivalent to banning the sale of Class E washing machines as categorised the current PROCEL system.<br>— EE Standard 2. Savings consist of 10%, 20% and 30% of business-as-usual energy consumption in 2015, 2020 and 2025 respectively. Based on the energy consumption of different classes of washing machines in ISIS (2007), this |

| Measure | Summary and key assumptions |
|---|---|
| **Energy efficient washing machines** | is approximately equivalent to banning the sale of Class D and E washing machines as categorised the current PROCEL system.<br><br>Energy savings are calculated over a fifteen year lifetime, and based on 4 cold washes of 7kg each per week per household, using an automatic frontloading machine. Observed prices online and in outlet stores in Sao Paolo suggested that price differentials among washing machines are not based significantly on energy efficiency ratings. In the absence of standard price differences and with an observed price range of BRL2,100-3,000 for an 8.5kg front loading model, an additional cost of BRL300 was assumed with EE1 standards and of BRL600 with EE2 standaards. This is conservative, since highly efficient options were available at no significant additional cost. |
| **Energy management of appliances** | Stand-by and low-power-mode use by consumer electronics is re- sponsible for about 10 % of residential and service power demand in Brazil (Volpi *et al.*, 2006). Savings from energy management are therefore based on saving 5% of residential power demand in Recife. |
| **Passive cooling building design** (high albedo surfaces) | Adopting high albedo surfaces refers to covering external surfaces with whitewashed acrylic latex coating to reflect heat. This is estimated to reduce heat gain and therefore cooling loads from south-oriented horizontal surfaces by 57% in Recife for a typical building (walls are assumed to be made of 100-mm thick ceramic blocks covered with 10-mm plaster layers on both sides (U = 1.8–2.5 $W/m^2 K$), while the building slab made of dry gravel concrete was 100 mm thick (U = 2–2.79 $W/m^2 K$))), (Oliviera et al., 2009). There is no increase in building costs. Energy savings are calculated to 2040. |
| **Passive cooling building design** (insulation) | Installing 20mm cotton wool insulation boards in new buildings would reduce heat gain and therefore cooling loads by 55% by 57% in Recife for a typical building (walls are assumed to be made of 100-mm thick ceramic blocks covered with 10-mm plaster layers on both sides (U = 1.8–2.5 $W/m^2 K$), while the building slab made of dry gravel concrete was 100 mm thick (U = 2–2.79 $W/m^2 K$) (Oliviera *et al.*, 2009). A cost of USD 2/$m^2$ is used based on wholesale average costs from Alibaba.com. Energy savings are calculated to 2040. |
| **Passive cooling building design** (evaporative cooling via porous roofs) | Establishing evaporative cooling reduces heat gain and therefore cooling loads from horizontal surfaces (roofs) by 67% in Recife for a typical building (walls are assumed to be made of 100-mm thick ceramic blocks covered with 10-mm plaster layers on both sides (U = 1.8–2.5 $W/m^2 K$), while the building slab made of dry gravel concrete was 100 mm thick (U = 2–2.79 $W/m^2 K$) (Oliviera et al., 2009). In this example, we have modelled low cost porous roofs (such as porous silica, expanded shale, coconut coir or shredded tires) as the evaporative cooling technique. The porous layer retains rainwater, which is released via evaporation in the heat. The evaporation releases latent heat, reducing the daily temperature of the roof by 6.8-8.6°C and correspondingly reducing heat flux from the roof slab to the building's interior (Wanphen and Nagano, 2009). This option has been selected because it is has less structural challenges due to its light weight than a green roof (i.e. one covered with vegetation), as well as requiring less maintenance. Some of the roof materials are freely available, but cost is assumed to be USD 1/$m^2$. Shallow water ponds and water towers would be alternative evaporative cooling strategies. Energy savings are calculated to 2040. |



| Measure | Summary and key assumptions |
|---|---|
| **Passive cooling building design (high albedo and evaporative cooling)** | Combining high albedo and evaporating cooling strategies is estimated to reduce heat gain and therefore cooling loads from south-oriented horizontal surfaces by 91% in Recife for a typical building (specified above), (Oliviera *et al.*, 2009). The costs incurred are equal to those with evaporative cooling techniques (no extra costs associated with high albedo surfaces). Energy savings are calculated to 2040. |
| **Setting LED target** | Savings consist of saved energy if a target of 50% LED lighting is effectively realised in residential buildings by 2030. The model assumes the existing ban on incandescent light bubs has been effective (a conservative assumption since up to 50% of Brazilian households still had incandescent bulbs in their house in 2013, according to Vahl *et al.* (2013)) and that LED bulbs would achieve 25% market penetration irrespective of policy interventions, based on falling production costs and improving luminosity. The average CFL light bulb is assumed to be 24W, being replaced a LED bulb of 15W. An LED light bulb in 2014 has a cost of R$130 and a lifespan of 50,000 hours; a CFL light bulb in 2014 has a cost of R$18 and a lifespan of 5,500 hours (Vahl *et al.*, 2013). |
| **Solar PV panel: a-Si** (amorphous silicon) | Solar panel assumed to cover 95% of a roof (average size 288$m^2$). Average conversion efficiency of 6.3%. Average generation of 20MWh per household. Electricity feeds into the public grid 30% of the time (Ordenesa *et al.*, 2007). Two scenarios are modelled:<br><br>— Target of 10% of households with solar PV panels.<br>— Target of 20% of households with solar PV panels.<br><br>The price of a 3kWp a-Si solar PV panel in the residential sector is based on the minimum technology costs in EPE (2012) (due to the low conversion efficiency of the technology), plus 20% installation, fee and import tax costs. No feed-in tariff is considered because the cost per MWh of rooftop solar is already below retail electricity prices (FS-UNEP and BNEF, 2014). We assume a lifespan of 20 years for each solar PV panel. |
| **Solar PV panel: HIT** (heterojunction comprised of a thin a-Si PV cell on top of a c-Si cell) | Solar panel assumed to cover 95% of a roof (average size 288m2). Average conversion efficiency of 17%. Average generation of 51.3MWh per household. Electricity feeds into the public grid 30% of the time (Ordenesa et al., 2007).<br><br>— Target of 10% of households with solar PV panels.<br>— Target of 20% of households with solar PV panels.<br><br>The price of a 3kWp HIT solar PV panel in the residential sector is based on data in ABINEE (2012), which does not specify the technology but has a comparable conversion efficiency. No feed-in tariff is considered because the cost per MWh of rooftop solar is already below retail electricity prices (FS-UNEP and BNEF, 2014). We assume a lifespan of 20 years for each solar PV panel. |
| **Turning off lights** | Savings consist of the energy used for one hour of lighting per day. The average light bulb in the domestic sector is used for an estimated five hours per day (Pereira and de Assis, 2013). |

## The Transport Sector

| Measure | Summary and key assumptions |
|---|---|
| **Bike lanes (56km)** | We model the impacts of extending Recife's 20km of cycle lanes to 56km. Capital costs and maintenance costs are estimated using the Bogota Cicloruta as a case study (C40, 2013). Impacts on transport modal share are estimated from a combination of focus groups, consultation with members of the transport industry in Recife, the C40 Bogota case study (2013) and academic literature on the impact of bike lanes on urban transport in a Brazilian context (Medeiros & Duarte, 2013). Information on the current biking scheme in Recife is drawn from local government agencies and ICLEI (GRT, 2014; ICLEI, 2014). |
| **Bike sharing** (2x current scheme) | Recife current bike sharing scheme is doubled in size. The cost of expanding network and potential revenue streams from advertising and subscriptions are drawn from Dias (2010). This impact on transport modes in Recife is informed by focus groups, consultation with members of the transport industry in Recife and academic literature on cycling in Brazilian cities (Dias, 2010; Medeiros & Duarte, 2013). |
| **Bus Rapid Transit** (BRT) | For the planned, but incomplete North-South and East-West expansions, data on load factors, distance and capital costs are drawn from NTU (2013). Fuel efficiencies for the BRT were based on consultation with local stakeholders. Distance travelled per year is obtained from MINC (2013). An expansion of the current network by 20km is modelled using the average capital costs and ridership figures per km from the North-South and East-West expansions. Efficiency factors for this expansion, as well as operating costs are drawn from Lindau (2013) and Duduta (2012). |
| **CNG taxis** (100% by 2030) | Petrol taxis are converted to CNG progressively over the period 2015-2030. Capital costs are estimated through consultation. Efficiency values for vehicles converted to CNG are drawn from Colnago (2011). The number of taxis and their age distribution in Recife is drawn from local government agencies (DETRAN, 2014; GRT 2014). The proportion of taxis that are currently CNG and the average distance travelled per month are obtained from personal consultation. Vehicle efficiency factors are drawn from the ICLEI emissions inventory for Recife and the Ministério de Minas e Energia and Empresa de Pesquisa Energética, Companhia Brasileira de Trens Urbanos (EPE, 2009, 2013a) |
| CNG vehicles — 50% by 2030 | 50% of petrol passenger vehicles are retrofit to petrol-CNG by 2030. Efficiency values for vehicles converted to CNG are drawn from Colnago (2011). Vehicle numbers, type and age are drawn from the ICLEI emissions inventory data and (CBTU, 2013; GRT 2014). Vehicle efficiency factors are otbained from the ICLEI emissions inventory for Recife and the Ministério de Minas e Energia and Empresa de Pesquisa Energética, Companhia Brasileira de Trens Urbanos (EPE, 2009, 2013a). |
| **Converting bus fleet to CNG, hybrids or biodiesel by 2030** | Recife's diesel bus fleet is converted progressively over the period 2015-2030 to CNG, hybrid or biodiesel buses. Data on Recife's current bus fleet, vehicle efficiencies and rate of vehicle turnover are found in the ICLEI emissions inventory and acquired from local government agencies (CBTU, 2013; EMTU, 1997, GRT 2014). CNG, hybrid and biodiesel technologies are chosen as alternative technologies to be assessed through consultation with members of the Recife transport agency, CBTU, and from a review of case studies of alternative bus technologies in Brazilian cities (D'Agosto, 2011-2013). Capital costs, maintenance costs, vehicle efficiencies and operating lifespans are drawn from Brazilian case studies (D'Agosto, 2011-2013). |



| Measure | Summary and key assumptions |
|---|---|
| **EU carbon emission vehicle standards** | We model the impact of Brazil adopting EU standards for carbon emissions from passenger vehicles and light trucks (ICCT, 2014). The rate of vehicle turnover is derived from data on the distribution of the vehicle stock by age in Recife DETRAN (2014), and the rate of change of the total vehicle stock in Recife (CBTU, 2013; GRT 2014). Results are modelled against a baseline scenario in which the fleet maintains its historic rate of improvement in fuel efficiency (Wills, 2010; Melo, 2010). |
| **Increase in bus service** (diesel, CNG and hybrid options) | In these measures Recife's bus fleet is expanded progressively over the period 2015-2030 20% or 40%, with either CNG, hybrid or conventional diesel buses. Data on Recife's current bus fleet, vehicle efficiencies and rate of vehicle turnover are found in the ICLEI emissions inventory and acquired from local government agencies (CBTU, 2013; EMTU, 1997, GRT 2014). CNG and hybrid technologies are chosen as alternative bus technologies to be assessed through consultation with members of the Recife transport agency, CBTU, and from a review of case studies of alternative bus technologies in Brazilian cities (D'Agosto, 2011-2013). Capital costs, maintenance costs, vehicle efficiencies and operating lifespans are drawn from Brazilian case studies (D'Agosto, 2011-2013). |
| **Investments to increase public transit use and safety** | Public safety concerns emerged from the workshops as a major concern of public transit users, and a barrier to increasing ridership. We therefore evaluate the impact of a bundle of safety improvement, including improved lighting, sidewalk extensions, security alarms installed at the most dangerous locations and increased police presence, are modelled. Cost and impacts on ridership are estimated based on consultation based on conservative assumptions of the potential for modal shift towards public transport. |
| **Mandatory fuel efficiency labelling** | In this measure the impact of Brazil's voluntary labelling program being made mandatory is modelled for Recife. Key academic literature investigating Brazil's labelling program (Wills, 2010; Novgorodcev, 2010), as well as personal consultation, inform the expected impact on vehicle purchases in Recife. Results are modelled against a baseline scenario in which the fleet maintains its historic rate of improvement in fuel efficiency (Wills, 2010; Melo, 2010). |
| **Metro expansion** | The existing metro is expanded 10km through Recife's downtown core. Capital costs are estimated based on the per km cost of Sao Paulo's recent metro expansion (Railway Gazette, 2013). Maintenance and operation costs, and ridership numbers are drawn from figures for the existing metro, consultation with local government, figures from the existing metro system in Recife and analysis from the World Bank (CBTU, 2013; EMTU, 1997, GRT 2014; Soares *et al.* 2011). |
| **Subsidy for scrapping old vehicles** | In these measures a subsidy of USD1,000 is provided to vehicle owners for retiring vehicles more than 20 years old, a fraction which currently represents nearly 20% of vehicles. Two versions of this measure are presented. In the first, the subsidy is conditional only on proof of retiring the vehicle. In the second version, the subsidy is conditional on purchasing a hybrid replacement vehicle. Travel distances by vehicle age are drawn from Szwarcfiter *et al.* (2005). The number of vehicles of different ages in Recife was drawn from DETRAN (2014). The anticipated effect of a USD1,000 subsidy was informed by academic literature (Dill, 2004; Kavalec, 1997) and consultation with local stakeholders from the transport sector. |

### The Transport Sector

*continued*

| Measure | Summary and key assumptions |
|---|---|
| **Street metering expansion** | Parking prices in central district of Recife are raised 57% in order to incentive alternative transport and raise funds for transit investments. Current parking availability and cost data are acquired through consultation with local experts. The cost of installing meters and the potential impact on transport in urban Recife are informed by a study of parking management in Curibita, Brazil and academic literature on intelligent parking management in Brazil (Berenger *et al.*, 2004; Ziemann et al., 2006). |
| **Teleworking** | Government employees are ordered to work from home for one day per week. Average commuting distance is drawn from Pereira (2013) and government employee numbers are accessed through consultation with stakeholder panels. The average work year is expected to be 200 days. Transportation modes and vehicle efficiency factors are drawn from the ICLEI emissions inventory for Recife, Ministério de Minas e Energia and Empresa de Pesquisa Energética, Companhia Brasileira de Trens Urbanos, and local government transportation agencies (EPE, 2009, 2013a; CBTU, 2013; EMTU, 1997, GRT 2014). |



### The Waste Sector

| Measure | Summary and key assumptions |
|---|---|
| **Centralised composting** | Organic material comprises approximately 55% of waste produced in Recife and approximately 75% of organic waste originates from food waste in the household sector. These characteristics of landfill waste in Recife lead to an unusually high methane generation potential (0.039).<br><br>Centralised composting assumes a 120,000 tonnes/year aerobic biological treatment plant. The carbon emissions savings calculations are based on IPCC (2006) and European Communities (2001). It is assumed that the feedstock to the composting plant will comprise good quality, source separated organic waste (food and garden). The participation and capture rates are based on WRAP (2009, 2011)<br><br>Capital and operational costs are based on Brazilian case studies of composting projects with conservative assumptions surrounding behavioural changes on the part of the general public (World Bank, 2010; Barreira 2008; Motta 2010). The assessments consider a revenue source from the sale of the compost, with current international compost prices and 30% of organic waste to be converted to compost. |
| **Energy from waste** | Savings from this measure are calculated assuming a 200,000 tonnes/ year thermal treatment plant with energy generation potential. One scenario is based on electricity only recovery and another on Combined Heat and Power (CHP) generation. Calculations of electricity and heat generation potentials and carbon emissions saved by energy displaced are based on IPCC (2006), European Communities (2001) and Gohlke (2007). Capital and operational costs are based on Brazilian projects (Souza *et al.*, 2014; IRENA 2012; ESMAP, 2010). Emissions resulting from the construction of the plant are derived from Brogaard (2013). |
| **Home composting** | Home composting assumes aerobic biological treatment of organic waste within the household and characteristics of the program proposed for Recife are based on Sao Paulo's 'Composta Sao Paulo' Program (Morada da Floresta, 2014). Potential yield factors were drawn from expert consultation and WRAP (2009, 2011). The carbon emissions savings calculations are based on IPCC (2006) and European Communities (2001). The participation and capture rates are based on WRAP (2009). |
| **Hybrid waste collection vehicle retrofit** | Recife's 150 diesel waste vehicles are converted to hybrid technology. Capital cost, operational efficiencies, running costs and maintenance costs are drawn from academic literature reviewing similar projects in Brazilian cities (Oliviera *et al.*, 2014; Rodrigues, 2010) |
| **Incineration** | Mass burn incineration assumes a 200,000 tonnes/year thermal treatment plant without energy generation potential. Carbon emissions saved by energy displaced are based on IPCC (2006) and European Communities (2001) and Gohlke (2007). The capital and operational costs are based on Brazilian case studies of waste incineration projects (Souza et al., 2014; IRENA 2012; ESMPA, 2010). Emissions resulting from the construction of plant derived from Brogaard (2013). |

## The Waste Sector

*continued*

| Measure | Summary and key assumptions |
|---|---|
| **Landfill gas utilisation** | This measure assumes 75% landfill gas collection efficiency (Yang, 2010; Niskanen 2013) and a 10% oxidation factor due to landfill cover (Manfredi *et al.*, 2009). Electricity generation from LFG and CO2-e and carbon emission reductions from displaced energy are calculated based on academic literature (World Bank, 2005; Gohlke, 2007). 10% of the electricity generated is used on site. Capital and operational costs are based on Brazilian case studies and academic literature (Souza *et al.*, 2014; Cruz and Paulino, 2013; World Bank, 2005; Loureiro 2013). Generator efficiencies are drawn from CCE (2000). |
| **Landfill gas flaring** | Capital and operational costs are based on Brazilian case studies of LFG flaring projects (World Bank, 2005; IRENA, 2010; Cruz and Paulino, 2013; Souza *et al.*, 2014). Savings are calculated based on 20% landfill gas collection efficiency and an oxidation factor of 10% due to landfill cover (World Bank, 2005; Souza *et al.*, 2014). |
| **Recycling program** | This measure is relevant to paper, plastics, metals and glass and includes an 80,000 tonnes/year materials recycling facility. This scenario assumes separate collection of comingled recyclables and considers the additional carbon emissions and costs associated with the separate collection. The revenue from the sale of the recyclables is based on prices at international trading sites at the time of the assessment. Capital and operation costs are based on European case studies and the Brazilian National Policy on Solid Waste (NLWA, 2013; WRAP, 2013) |
| **Waste prevention** | The waste prevention scenario is relevant to packaging waste (paper and plastic) and assumes a final reduction of packaging of 5% or 10%. Costs of waste prevention campaigns and the cost savings from packaging waste prevention are based on successful UK case studies and the Brazilian National Policy on Solid Waste (NLWA, 2013; WRAP, 2013) |



## References for Appendix C


ABINEE. 2012. Propostas para Inserção da Energia Solar Fotovoltaica na Matriz Elétrica Brasileira. Associação Brasileira da Indústria Elétrica e Eletrônica. Available from <http://www.abinee.org.br/informac/arquivos/profotov.pdf > [viewed 21/10/2014]

Achão C, Schaeffer R. 2009. Decomposition analysis of the variations in residential electricity consumption in Brazil for the 1980–2007 period: Measuring the activity, intensity and structure effects. Energy Policy. 37(12) 5208–5220

Barreira LP, Philippi Junior A, Tenório JA. 2008. Physical analyses of compost from composting plants in Brazil. Waste Management. 28(8) 1417-1422.

Berenger V, Marinho M, da Silva Portugal L, Balassiano R. 2004. Intelligent transportation systems and parking management: implementation potential in a Brazilian city. Cities 21(2) 137-148.

Brogaard, LK, Riber C, Christensen TH. 2013. Quantifying capital goods for waste incineration. Waste Management. 33(6) 1390-1396.

C40. 2013. Bogotá's CicloRuta is One of the Most Comprehensive Cycling Systems in the World. Available from <http://www.c40.org/case_studies/bogot%C3%A1%E2%80%99s-cicloruta-is-one-of-the-most-comprehensive-cycling-systems-in-the-world> [viewed 28/11/2014]

Cardoso RB, Horta Nogueira LA, Haddad J. 2010. Economic feasibility for acquisition of efficient refrigerators in Brazil. Applied Energy. 87(1) 28-37

Cardoso RB, Horta Nogueira LA, Palhares de Souza E, Haddad J. 2012. An assessment of energy benefits of efficient household air-conditioners in Brazil. Energy Efficiency. 5 433-446

Carvalho MMQ, La Rovere EL, Gonçalves ACM. 2010. Analysis of variables that influence electric energy consumption in commercial buildings in Brazil. Renewable and Sustainable Energy Reviews. 14(9) 3199-3205

CBTU 2013. Companhia Brasileira de Trens Urbanos. Recife. Available from <http://www.cbtu.gov.br/images/relatorios/gestao2013.pdf> [viewed 28/11/2014]

CCE. 2000. Technical Biogas Guide. Center for Energy Conservation. Lisbon, Portugal: Paulo Santos, General Energy Directorate (DGR).

Cruz SS, Paulino SR. 2013. Local use of resources from clean development mechanism projects in landfill sites in the city of São Paulo. Ambiente & Sociedade 16(1) 117-140.

Colnago K, Vicentini PC. 2011. Emissions from Light Vehicles Adapted with CNG kit the Metropolitan Area of Rio de Janeiro. No. 2011-36-0241. SAE Technical Paper.

De Almeida A, Hirzel S, Patrão, Fong J, Dütschke E. 2012. Energy-efficient elevators and escalators in Europe: An analysis of energy efficiency potentials and policy measures. Energy and Buildings. 47 151-158

D'Agosto MA, Souza CDR. 2011. CNG in Urban Transport: Usage in the Cities of Rio de Janeiro, Duque de Caxias and Nova Iguacu. Rio de Janeiro, Brazil: COPPE/UFRJ.

D'Agosto MA, Souza CDR, Silva SD, Barboza AP, Almeida MLR. 2012. Technological Alternatives for Buses in Rio de Janeiro. Rio de Janeiro, Brazil: COPPE/UFRJ.

D'Agosto MA, Ribeiro SK, Ribeiro de Souza CD. 2013. Opportunity to reduce greenhouse gas by the use of alternative fuels and technologies in urban public transport in Brazil. Current Opinion in Environmental Sustainability. 5(2) 177-183.

da Costa, SS. 2014. National Policy on Solid Waste. Available from <http://www.reinnova.es/pdf/06.02%20Silvano%20Silverio%20Da%20Costa.pdf> [viewd 27/11/2014]

da Motta RS, Hargrave J, Luedemann G, Gutierrez MBS. 2010. Climate Change in Brazil: Economic, social and regulatory aspects. Available from <http://www.ipea.gov.br/portal/images/stories/PDFs/livros/livros/livro_climatechange_ingles.pdf> [viewed 28/11/2014]

de Melo CA, de Martino Jannuzzi G. 2010. Energy efficiency standards for refrigerators in Brazil: A methodology for impact evaluation. Energy Policy. 38(11) 6545-6550

de Oliveira, LA de Almeida D'Agnosta, M, Fernandes VA, de Oliveira M. 2014. A financial and environmental evaluation for the introduction of diesel-hydraulic hybrid-drive system in urban waste collection. Transportation Research Part D: Transport and Environment. 31 100-109.

de Oliveira JT, Hagishima A, Tanimoto J. 2009. Estimation of passive cooling efficiency for environmental design in Brazil. Energy and Buildings. 41(8) 809-813

DETRAN 2014. Table 1.13 - Frota de Veículos, segundo a idade, Pernambuco. Government of Pernambuco. Available from <http://www.detran.pe.gov.br/images/stories/estatisticas/HP/1.13_idade_frota.pdf> [viewed 28/11/2014]

Dias Batista E. 2010. Bicycle Sharing in Developing Countries: A proposal towards sustainable transportation in Brazilian median cities. Available from <http://kth.diva-portal.org/smash/get/diva2:471450/FULLTEXT01.pdf> [viewed 28/11/2014]

Dill J. 2004. Estimating emissions reductions from accelerated vehicle retirement programs. Transportation Research Part D: Transport and Environment 9(2) 87-106

Duduta N, Adriazola C, Hidalgo D, Lindau LA, Jaffe R. 2012. Understanding Road Safety Impact of High-Performance Bus Rapid Transit and Busway Design Features. Transportation Research Record: Journal of the Transportation Research Board. 2317(1) 8-14.

Department of Energy. 2011. Report on the First Quadrennial Technology Review. USA. Available from <http://energy.gov/sites/prod/files/ReportOnTheFirstQTR.pdf> [viewed 13/11/2014]

Department of Energy. 2014. Retrofit financial analysis tool, version 1.1.01. USA. Available from <http://energy.gov/eere/ssl/downloads/retrofit-financial-analysis-tool-version-1101> [viewed 10/11/2014]

e4 Project. 2010. Methodology of Energy Measurement and Estimation of Annual Energy Consumption of Lifts (Elevators), Escalators and Moving Walkways. Available from <http://www.e4project.eu/Documenti/WP3/E4_WP3%20D3.2%20Report%20Final-2.pdf> [viewed 10/11/2014]

Electrobras. 1998. Pesquisa de posse de eletrodomésticos e hábitos de consumo (Survey on household appliances ownership and electricity consumption). Electrobras, PROCEL, PUC-Rio, Brazil.

EMTU. 1997. Pesquisa da RMR sobre Transporte Público de Passageiros. Relatório Final. Volume 1, Recife: EMTU.

EPE. 2012. Análise da Inserção da Geração Solar na Matriz Elétrica Brasileira. Available at <http://www.epe.gov.br/geracao/Documents/Estudos_23/NT_EnergiaSolar_2012.pdf> [viewed 21/10/2014]

European Communities. 2001. Waste Management Options and Climate Change. Available from <http://ec.europa.eu/environment/waste/studies/pdf/climate_change.pdf> [viewed 10/09/2014]

FS-UNEP and BNEF (2014). Global Trends in Renewable Energy Investment 2014. Frankfurt School–UNEP Collaborating Centre for Climate & Sustainable Energy Finance and Bloomberg New Energy Finance. Available from <http://fs-unep-centre.org/publications/gtr-2014> [viewed 21/10/2014]

Geller H, de Martino Jannuzzi G, Schaeffer R, Tolmasquim MT. 1998. The efficient use of electricity in Brazil: progress and opportunities. Energy Policy. 26(11) 859-872 DOI: 10.1016/S0301-4215(98)00006-8

Gohlke O, Martin J .2007. Drivers for innovation in waste-to-energy Technology. Waste Management & Research. 25 214 –219.

GRT. 2014. Grande Recife Transporte. Government of Pernambuco. Available from <http://www.granderecife.pe.gov.br/web/grande-recife/evolucao-de—passageiros-transportados-equivalente> [viewed 21/10/2014]

Harvey LDD. 2009. Reducing energy use in the buildings sector: measures, costs, and examples. Energy Efficiency. 2 139-163. DOI: 10.1007/s12053-009-9041-2

ICLEI 2014. Suwon and Recife tackle urban traffic with ecomobility. Available from <http://www.iclei.org/details/article/suwon-and-recife-tackle-urban-traffic-with-ecomobility.html> [viewed 28/11/2014]

International Council on Clean Transportation. 2014. EU CO2 standards for passenger cars and light-commercial vehicles. Available from <http://www.theicct.org/sites/default/files/publications/ICCTupdate_EU-95gram_jan2014.pdf> [viewed 5/02/2014]

IPCC. 2006a. Guidelines for National Greenhouse Gas Inventories. Volume 5: Waste. Available from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf> [viewed 30/10/2014]

IRENA. 2010. Brazil Low Carbon Case Study. Technical Synthesis Report. International Renewable Energy Agency. Available from <http://www.esmap.org/sites/esmap.org/files/Waste_English_final_09-12.pdf> [viewed 6/10/2014]

IRENA 2012. Waste to Energy for More Effective Landfill Site Management. International Renewable Energy Agency. Belo Horizonte, Brazil. Available from <http://www.irena.org/Publications/RE_Policy_Cities_CaseStudies/IRENA%20cities%20case%203%20Belo%20Horizonte.pdf> [viewed 6/10/2014]

ISIS. 2007. Lot 14: Domestic Washing Machines and Dishwashers. Preparatory Studies for Eco-design requirements of EuPs (Tender TREN/D1/40-2005). Available from <http://www.atlete.eu/doc/eco/Lot%2014%20Draft%20Final%20Report%20tasks%201-2.pdf> [viewed 20/10/2014]

Kavalec C, Setiawan W. 1997. An analysis of accelerated vehicle retirement programs using a discrete choice personal vehicle model. Transport Policy 4(2) 95-107.

Lindau LA, Pereira BM, de Castilho RA, Diógenes MC, Herrera Maldonado, JC. 2013. Exploring the performance limit of a single lane per direction Bus Rapid Transit 1 Systems (BRT) 2. Transportation Research Board. 92nd Annual Meeting. 13(1412)

Loureiro SM, Rovere ELL, Mahler CF. 2013. Analysis of potential for reducing emissions of greenhouse gases in municipal solid waste in Brazil, in the state and city of Rio de Janeiro. Waste Management. 33(5) 1302-1312.

Manfredi S, Tonini D, Christensen TH, Scharff H. 2009. Landfilling of waste: accounting of greenhouse gases and global warming contributions. Waste Management Resources. 27: 825

McNeil MA, Letschert VE. 2008. Future air conditioning energy consumption in developing countries and what can be done about it: the potential of efficiency in the residential sector. Lawrence Berkeley National Laboratory. Available from <http://escholarship.org/uc/item/64f9r6wr> [viewed 16/10/2014]

McNeil MA, Letschert VE. 2010. Modeling diffusion of electrical appliances in the residential sector. Energy and Buildings. 42(6) 783–790

Medeiros RM, Duarte F. 2013. Policy to promote bicycle use or bicycle to promote politicians? Bicycles in the imagery of urban mobility in Brazil. Urban, Planning and Transport Research 1(1) 28-39, DOI: 10.1080/21650020.2013.866875

Melo TC, Colnago K, Loureiro LN. 2010. An Overview of Brazilian New Emission and Fuel Legislation for Light Duty Vehicles. No. 2010-01-1570. SAE Technical Paper

Minc C. 2013. I Inventário Nacional de Emissões Atmosféricas por Veículos Automotores Rodoviários. Available from <http://www. mma. gov. br/estruturas/182/_arquivos/inventri o_de_emisses_veiculares_182.pdf> [viewed 28/11/2014]

Morada da Floresta. 2014. Composta Sao Paulo. Municipality of Sao Paulo. Available from <http://www.compostasaopaulo.eco.br/> [viewed 28/11/2014]

Naspolini HF, Militão HSG, Rüther R. 2010. The role and benefits of solar water heating in the energy demands of low-income dwellings in Brazil. Energy Conversion and Management. 51(12) 2835–2845

Niskanen A, Värri H, Havukainen J, Uusitalo V and Horttanainen M. 2013. Enhancing landfill gas recovery. Journal of Cleaner Production. 55: 67–71

NLWA. 2012. North London Waste Prevention Plan. North London Waste Authority. Available from <http://www.nlwa.gov.uk/docs/nlwa-general-documents-andplans/2012-14-waste-prevention-plan-final.pdf> [viewed 30/04/2014]

Novgorodcev A, Branco GM, Branco FC, Martin R, Alzuguir CG, Mainier F. 2010 Labelling and standards for light duty vehicles in Brazil improving energy efficiency and reducing CO2. Available from <http://www.fisita2010.com/programme/programme/pdf/F2010G007.pdf> [viewed 27/11/2014]

NTU. 2013. BRT Studies in Brasil. Brasilia. Available from <http://www.vivanext.com/files/TransitPanel/BRT%20Studies%20in%20Brazil.pdf> [viewed 17/10/2014]

Ordenesa M, Marinoskia DL, Brauna P, Rüthera R. 2007. The impact of building-integrated photovoltaics on the energy demand of multi-family dwellings in Brazil. Energy and Buildings. 39(6) 629–642

Park WY. 2011. TV Energy Consumption Trends and Energy-Efficiency Improvement Options. Lawrence Berkeley National Laboratory. Available from <http://escholarship.org/uc/item/8mk3d4k5> [viewed 20/10/2014]

Park WY, Phadke A, Shah N, Letschert V. 2013. Efficiency improvement opportunities in TVs: Implications for market transformation programs. Energy Policy. 59 361-372

Pereira IM, de Assis ES. 2013. Urban energy consumption mapping for energy management. Energy Policy. 59 257–269

Pereira, RHM, Schwanen T. 2013. Commute time in Brazil (1992-2009): Differences between metropolitan areas, by income levels and gender. No. 1813a. Texto para Discussão, Instituto de Pesquisa Econômica Aplicada (IPEA).

Railway Gazette. 2013. São Paulo Line 6 tender called. Railway Gazette. Available from <http://www.railwaygazette.com/news/single-view/view/sao-paulo-line-6-tender-called.html> [viewed 19/10/2014]

Rio Prefereitura Meio Ambiente. 2014. Energy Toolkit for Buildings: Solar Thermal Water Heating. Available from <http://www.riorenewables.com/renewable-technologies/solar-energy/solar-water-heating> [viewed 21/10/2014]

Rodrigues RS, 2010. Análise da Tecnologia Híbrida Hidráulica para Frota de Caminhões no Município de São Paulo. Dissertação de M. Sc., USP, São Paulo, SP, Brasil. Available from <http://www.automotivapoliusp.org.br/mest/banc/pdf/Rodrigo_Rodrigu es.pdf> [viewed 28/11/14]

Silva Alves JW, de Gouvello C, de Oliveira BP, Magalhães Cunha HC, Cunha Alves TL, Santo Filho FE, Gomes Cunha ME, Toshio E. 2010. Brazil Low Carbon Case Study: Waste. World Bank. Available from <http://www.esmap.org/sites/esmap.org/files/Waste_English_final_09-12.pdf> [viewed 27/11/2014]

Souza SN, Horttanainen M, Antonelli J, Klaus O, Lindino CA, Nogueira CE. 2014. Technical potential of electricity production from municipal solid waste disposed in the biggest cities in Brazil: Landfill gas, biogas and thermal treatment. Waste Management & Research. 32(10) 1015-1023.

Szwarcfiter L, Mendes FE, Rovere ELL. 2005. Enhancing the effects of the Brazilian program to reduce atmospheric pollutant emissions from vehicles. Transportation Research Part D: Transport and Environment. 10(2) 153-160.

The Climate Group. 2012. Global outdoor LED trials: Analysis for Lighting Managers. Available from <http://www.theclimategroup.org/_assets/files/LED-Report-Full-FINAL-low-res%281%29.pdf> [viewed 10/11/2014]

Vahl FP, Campos LMS, Filho NC. 2013. Sustainability constraints in techno-economic analysis of general lighting retrofits. Energy and Buildings. 67 500-507

Volpi G, Jannuzzi G, Gomes RDM. 2006. A sustainable electricity blueprint for Brazil. Energy for Sustainable Development. X(4) 14-24

Wanphen S, Negano K. 2009. Experimental study of the performance of porous materials to moderate the roof surface temperature by its evaporative cooling effect. Building and Environment. 44 338-351

Wills W, Rovere ELL. 2010. Light vehicle energy efficiency programs and their impact on Brazilian CO2 emissions. Energy Policy. 38(11) 6453-6462.

WRAP. 2009. Evaluation of the WRAP Separate Food Waste Collection Trials. Waste and Resources Action Programme. Available from <http://www.wrap.org.uk/sites/files/wrap/Evaluation_of_the_WRAP_FW_Col lection_Trials_Update_June_2009.pdf

WRAP. 2011. Comparing the cost of alternative waste treatment options. Waste and Resources Action Programme. Available from <http://www.uel.ac.uk/www-media/uel/migratedcontent/greenthing/documents/WRAPGateFeesReport2011.pdf> [viewed 30/04/2014]

WRAP. 2013. Waste prevention reviews in the food and drink sector. Waste and Resources Action Programme. Available from <http://www.wrap.org.uk/sites/files/wrap/Summary%20report%20-%20waste%20prevention%20reviews%20in%20the%20food%20and%20drink%20sector.pdf> [viewed 30/04/2014]

World Bank. 2005. Nova Gerar Landfill Rio de Janeiro. World Bank. Washington, DC. Available from <http://www.worldbank.org/projects/P079182/nova-gerar-landfill-rio-de-janeiro?lang=en> [viewd 27/11/2014]

World Bank. 2010. Estudo de Baixo Carbono para o Brasil : Relatório de Síntese Técnica - Resíduos. World Bank. Washington, DC. Available from <http://documents.worldbank.org/curated/en/2010/01/16475544/brazil-low-carbon-case-study-technical-synthesis-report-waste-estudo-de-baixo-carbono-para-o-brasil-relat%C3%B3rio-de-s%C3%ADntese-t%C3%A9cnica-res%C3%ADduos> [viewed 27/11/2014]

Yang N, Zhang H, Shao LM, Lü F, He PJ 2013. Greenhouse gas emissions during MSW landfilling in China: Influence of waste characteristics and LFG treatment measures. Journal of Environmental Management 129 510-521

Ziemann C. 2006. Is Curitiba, Brazil, the model city for parking management? Transportation Research Board. 88th Annual Meeting. No. 09)3841.




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

## Appendix D:

## League Table of the Most Cost-Effective Measures in Recife (USD/$tCO_2$-e)

| Rank | Sector | Measure: | BRL /$tCO_2$-e | USD /$tCO_2$-e |
|---|---|---|---|---|
| 1 | Commercial | Air conditioner (EE Standard 1) | -9,887.01 | -4,208.90 |
| 2 | Commercial | Air conditioner (EE Standard 2) | -8,040.84 | -3,422.99 |
| 3 | Transport | Converting 200 taxis to CNG by 2030 | -3,106.72 | -2141.76 |
| 4 | Transport | Increase in CNG bus service - 40% | -2,905.38 | -1468.21 |
| 5 | Transport | Increase in CNG bus service - 20% | -2,354.33 | -1406.15 |
| 6 | Transport | CNG vehicles - 10% by 2030 | -2,035.23 | -1347.99 |
| 7 | Residential | Passive cooling (evaporative cooling via porous roofs) | -1,920.56 | -1,322.53 |
| 8 | Residential | Refrigerator (EE Standard 2) | -1,840.90 | -1,236.82 |
| 9 | Residential | Turning off lights | -1,811.97 | -1,002.24 |
| 10 | Commercial | Turning off lights | -1,052.05 | -866.40 |
| 11 | Residential | Passive cooling (high albedo) | -1,001.20 | -817.58 |
| 12 | Commercial | LED street lighting | -911.75 | -783.67 |
| 13 | Residential | Passive cooling (high albedo and evaporative cooling via porous roofs) | -625.02 | -771.36 |
| 14 | Transport | Increase in hybrid bus service - 20% | -598.60 | -477.52 |
| 15 | Residential | Air conditioner (EE Standard 1) | -573.84 | -447.86 |
| 16 | Transport | Increase in hybrid bus service - 40% | -557.94 | -426.64 |
| 17 | Residential | Air conditioner (EE Standard 2) | -388.49 | -426.21 |
| 18 | Transport | EU carbon emission vehicle standards | -275.90 | -425.43 |
| 19 | Transport | Mandatory fuel efficiency labelling | -203.28 | -368.98 |
| 20 | Transport | Converting existing bus fleet to CNG by 2030 | -181.62 | -302.45 |
| 21 | Transport | BRT - North-South | -181.11 | -254.48 |
| 22 | Commercial | Setting LED target of 100% by 2030 (commercial buildings) | -157.07 | -237.51 |
| 23 | Transport | Teleworking | -128.76 | -223.75 |
| 24 | Transport | Street metering expansion | -113.91 | -209.43 |
| 25 | Waste | Energy from waste (combined heat and power) | -108.33 | -202.78 |
| 26 | Commercial | Setting LED target of 100% by 2030 (public buildings) | -95.25 | -165.38 |
| 27 | Transport | BRT - East-West | -89.15 | -163.67 |
| 28 | Waste | Hybrid waste collection retrofit | -86.32 | -151.26 |
| 29 | Waste | Energy from waste (electricity) | -76.13 | -134.70 |
| 30 | Residential | a-Si solar PV panel | -69.67 | -117.45 |
| 31 | Transport | Converting existing bus fleet to hybrid vehicles by 2030 | -64.39 | -112.41 |
| 32 | Residential | Setting LED target of 50% | -57.34 | -48.49 |
| 33 | Residential | HIT solar PV panel | -47.85 | -32.41 |
| 34 | Waste | LFG utilisation | -11.28 | -26.50 |
| 35 | Transport | Bike sharing | -2.28 | -2.76 |
| 36 | Residential | Energy management of appliances | -1.84 | -0.97 |
| 37 | Commercial | Elevators and escalators (EE Standard 1) | -1.84 | -0.78 |
| 38 | Commercial | Elevators and escalators (EE Standard 2) | -1.17 | -0.78 |

## Appendix D:
*continued*

| Rank | Sector | Measure: | BRL /$tCO_2$-e | USD /$tCO_2$-e |
|---|---|---|---|---|
| 39 | Residential | Television (EE Standard 2) | -0.11 | -0.05 |
| 40 | Residential | Television (EE Standard 1) | -0.09 | -0.04 |
| 41 | Waste | Waste prevention - 10% | 0.85 | 1.99 |
| 42 | Waste | Centralised composting | 1.20 | 2.81 |
| 43 | Waste | Waste prevention - 5% | 1.63 | 3.82 |
| 44 | Commercial | a-Si solar PV panel | 7.13 | 8.48 |
| 45 | Waste | LFG flaring | 10.18 | 16.75 |
| 46 | Waste | Recycling program - 40% | 19.93 | 23.91 |
| 47 | Waste | Home composting - 30% yield | 27.61 | 64.85 |
| 48 | Waste | Home composting - 15% yield | 29.08 | 68.30 |
| 49 | Waste | Recycling program - 20% | 33.91 | 79.65 |
| 50 | Commercial | HIT solar PV panel | 64.42 | 93.53 |
| 51 | Transport | Subsidy for scrapping old vehicles - hybrid voucher valued at USD1,000 | 91.25 | 151.32 |
| 52 | Transport | Converting existing bus fleet to biodiesel | 92.00 | 214.35 |
| 53 | Waste | Incineration | 106.74 | 216.11 |
| 54 | Transport | Bike lanes | 219.70 | 250.73 |
| 55 | Residential | Refrigerator (EE Standard 1) | 338.39 | 715.22 |
| 56 | Transport | Investments to increase public transit use and safety | 396.61 | 794.91 |
| 57 | Transport | BRT North-South and East-West capacity expansion | 459.74 | 931.66 |
| 58 | Residential | Passive cooling (thermal insulation) | 1,457.44 | 968.08 |
| 59 | Commercial | Green Building Standard 2 | 1,680.09 | 1,079.93 |
| 60 | Transport | Subsidy for scrapping old vehicles – cash payments of USD1,000 | 2,274.09 | 1,079.96 |
| 61 | Commercial | Green Building Standard 1 | 2,536.82 | 1,260.19 |
| 62 | Residential | Solar-assisted electric shower | 2,960.27 | 1,400.98 |
| 63 | Transport | Increase in bus service - 20% | 3,291.01 | 3,423.62 |
| 64 | Commercial | Double glazed reflective glass plus polystyrene insulation - retrofit commercial buildings | 10,697.62 | 7,990.62 |
| 65 | Commercial | Double glazed reflective glass plus polystyrene insulation - retrofit public buildings | 18,770.55 | 7,992.41 |
| 66 | Residential | Washing machine (EE Standard 1) | 18,774.74 | 12,942.99 |
| 67 | Residential | Washing machine (EE Standard 2) | 30,404.01 | 12,942.99 |
| 68 | Transport | Metro expansion | 30,404.01 | 25,129.48 |



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

## Appendix E:
## League Table of the Most Carbon-Effective Measures in Recife ($ktCO_2$-e)

| Rank | Sector | Measure: | $ktCO_2$-e |
|---|---|---|---|
| 1 | Waste | Centralised composting | 7,878.44 |
| 2 | Residential | Converting existing bus fleet to biodiesel | 7,467.92 |
| 3 | Waste | LFG utilisation | 4,333.67 |
| 4 | Transport | EU carbon emission vehicle standards | 4,140.15 |
| 5 | Waste | LFG flaring | 4,120.38 |
| 6 | Waste | Energy from waste (combined heat and power) | 3,661.55 |
| 7 | Waste | Incineration | 3,538.34 |
| 8 | Waste | Energy from waste (electricity) | 3,538.34 |
| 9 | Transport | Converting existing bus fleet to hybrids by 2030 | 3,006.82 |
| 10 | Waste | Home composting - 30% yield | 2,541.35 |
| 11 | Waste | Recycling program - 40% | 2,438.34 |
| 12 | Transport | Converting existing bus fleet to CNG by 2030 | 1,435.40 |
| 13 | Waste | Home composting - 15% yield | 1,297.15 |
| 14 | Waste | Waste prevention - 10% | 1,133.51 |
| 15 | Waste | Recycling program - 20% | 1,105.77 |
| 16 | Transport | Increase in hybrid bus service - 40% | 686.60 |
| 17 | Transport | Street metering expansion | 654.47 |
| 18 | Waste | Waste prevention - 5% | 590.67 |
| 19 | Transport | Increase in CNG bus service - 40% | 394.16 |
| 20 | Commercial | Air conditioner (EE Standard 2) | 393.52 |
| 21 | Transport | Increase in hybrid bus service - 20% | 373.89 |
| 22 | Residential | HIT solar PV panel - 10% of households by 2030 | 225.56 |
| 23 | Transport | Increase in CNG bus service - 20% | 224.41 |
| 24 | Residential | Air conditioner (EE Standard 2) | 212.11 |
| 25 | Commercial | Air conditioner (EE Standard 1) | 196.76 |
| 26 | Residential | Air conditioner (EE Standard 1) | 169.33 |
| 27 | Residential | Energy management of appliances | 157.31 |
| 28 | Commercial | Green Building Standard 2 - 100% of new buildings | 121.55 |
| 29 | Residential | HIT solar PV panel - 5% of households by 2030 | 112.78 |
| 30 | Transport | BRT - North-South | 111.80 |
| 31 | Commercial | Setting LED target of 100% by 2030 (commercial buildings) | 109.09 |
| 32 | Residential | Turning off lights | 100.77 |
| 33 | Transport | BRT - East-West | 96.94 |
| 34 | Transport | Bike lanes (56km) | 94.35 |
| 35 | Residential | Refrigerator (EE Standard 2) | 93.87 |
| 36 | Residential | a-Si solar PV panel - 10% of households by 2030 | 83.59 |
| 37 | Transport | Bike sharing (2x current scheme) | 78.63 |
| 38 | Transport | Metro expansion | 78.33 |
| 39 | Transport | Converting 200 taxis to CNG by 2030 | 72.04 |

## Appendix E:
*continued*

| Rank | Sector | Measure: | $ktCO_2$-e |
|---|---|---|---|
| 40 | Transport | Increase in bus service - 20% | 67.00 |
| 41 | Commercial | Turning off indoor lights | 66.41 |
| 42 | Residential | Television (EE Standard 2) | 66.11 |
| 43 | Transport | Investments to increase public transit use and safety | 62.90 |
| 44 | Residential | Television - EE Standard 1 | 61.35 |
| 45 | Commercial | Green Building Standard 2 - 50% of new buildings from 2015 | 60.77 |
| 46 | Commercial | Green Building Standard 1 - 100% of new buildings from 2015 | 60.77 |
| 47 | Residential | Passive cooling (high albedo and evaporative cooling via porous roofs) - Scenario 2, BAU | 54.56 |
| 48 | Residential | a-Si solar PV panel - 5% of households by 2030 | 41.80 |
| 49 | Residential | Solar-assisted electric shower - 40% of households by 2030 | 39.99 |
| 50 | Transport | Subsidy for scrapping old vehicles - hybrid voucher valued at USD1,000 | 39.48 |
| 51 | Residential | Passive cooling (high albedo) - Scenario 2, BAU | 34.18 |
| 52 | Residential | Passive cooling (thermal insulation) - Scenario 2, BAU | 32.98 |
| 53 | Commercial | Green Building Standard 1- 50% of new buildings from 2015 | 30.39 |
| 54 | Residential | Setting LED target of 50% | 29.09 |
| 55 | Waste | Hybrid waste collection retrofit | 28.11 |
| 56 | Commercial | HIT solar PV panel - additional 20MW by 2030 | 27.63 |
| 57 | Residential | Passive cooling (evaporative cooling via porous roofs) - Scenario 1, BAU | 21.29 |
| 58 | Transport | BRT North-South and East-West capacity expansion | 20.33 |
| 59 | Residential | Solar-assisted electric shower - 20% of households by 2030 | 19.99 |
| 60 | Residential | Refrigerator - EE Standard 1 | 19.72 |
| 61 | Transport | CNG vehicles - 10% by 2030 | 18.69 |
| 62 | Residential | Passive cooling (high albedo and evaporative cooling via porous roofs) - Scenario 1, BAU | 17.09 |
| 63 | Residential | Passive cooling (high albedo) - Scenario 1, BAU | 17.09 |
| 64 | Residential | Passive cooling (thermal insulation) - Scenario 1, BAU | 16.49 |
| 65 | Residential | Passive cooling (evaporative cooling via porous roofs) - Scenario 2, BAU | 15.56 |
| 66 | Transport | Subsidy for scrapping old vehicles - cash payments of USD1,000 | 13.83 |
| 67 | Commercial | HIT solar PV panel - additional 10MW by 2030 | 13.81 |
| 68 | Commercial | Double glazed reflective glass plus polystyrene insulation - retrofit 20% of commercial buildings | 13.76 |
| 69 | Commercial | Elevators and escalators (EE Standard 2) | 13.37 |
| 70 | Transport | Mandatory fuel efficiency labelling | 11.85 |
| 71 | Commercial | LED street lighting | 11.64 |
| 72 | Commercial | a-Si solar PV panel - additional 20MW by 2030 | 10.24 |
| 73 | Commercial | Setting LED target of 100% by 2030 (public buildings) | 7.84 |
| 74 | Commercial | Double glazed reflective glass plus polystyrene insulation - retrofit 10% of commercial buildings | 6.88 |
| 75 | Commercial | Elevators and escalators (EE Standard 1) | 6.69 |
| 76 | Commercial | a-Si solar PV panel - additional 10MW by 2030 | 5.12 |
| 77 | Commercial | Double glazed reflective glass plus polystyrene insulation - retrofit 100% of public buildings | 5.06 |



## Appendix E:
*continued*

| Rank | Sector | Measure: | $ktCO_2$-e |
|---|---|---|---|
| 78 | Residential | Washing machine (EE Standard 2) | 2.89 |
| 79 | Commercial | Double glazed reflective glass plus polystyrene insulation - retrofit 50% of public buildings | 2.53 |
| 80 | Residential | Washing machine (EE Standard 1) | 1.45 |
| 81 | Transport | Teleworking | 0.54 |

Cost effective

Cost neutral

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

## Appendix F:

### League Table of the Most Socially, Politically and Environmentally Acceptable Measures in Recife

| Rank | Sector | Measure | Political acceptability | Public acceptability | Capacities for implementation | Impact on human development | Impact on environment | Weighted score |
|---|---|---|---|---|---|---|---|---|
| 1 | Transport | Bike sharing | 3.9 | 4.2 | 4.1 | 4.7 | 4.7 | 4.17 |
| 2 | Transport | Investments to increase public transit use and safety | 4.0 | 4.3 | 3.9 | 4.8 | 4.4 | 4.14 |
| 3 | Residential | Air conditioner (EE Standard 1) | 4.5 | 4.5 | 4.5 | 2.9 | 3.0 | 4.11 |
| 4 | Residential | Air conditioner (EE Standard 2) | 4.5 | 4.5 | 4.5 | 2.9 | 3.0 | 4.11 |
| 5 | Residential | Refrigerator (EE Standard 2) | 4.3 | 4.3 | 4.5 | 2.9 | 2.9 | 3.98 |
| 6 | Residential | Refrigerator (EE Standard 1) | 4.3 | 4.3 | 4.5 | 2.9 | 2.9 | 3.98 |
| 7 | Transport | BRT – North South | 4.2 | 4.4 | 3.5 | 4.3 | 3.9 | 3.91 |
| 8 | Transport | BRT - East West | 4.2 | 4.4 | 3.5 | 4.3 | 3.9 | 3.91 |
| 9 | Transport | Bike lanes | 3.6 | 4.1 | 3.9 | 4.1 | 4.3 | 3.90 |
| 10 | Transport | Increase in bus service - 20% | 3.9 | 4.9 | 3.4 | 4.2 | 4.0 | 3.90 |
| 11 | Public and commercial | LED street lighting | 4.1 | 4.7 | 3.0 | 3.9 | 4.3 | 3.89 |
| 12 | Transport | BRT North-South and East-West capacity expansion | 4.0 | 4.4 | 3.5 | 4.3 | 3.9 | 3.88 |
| 13 | Transport | Metro expansion | 3.8 | 4.9 | 3.1 | 4.4 | 4.4 | 3.87 |
| 14 | Transport | Increase in bus service - 40% | 3.7 | 4.9 | 3.2 | 4.2 | 4.1 | 3.80 |
| 15 | Transport | Increase in hybrid bus service - 20% | 3.2 | 4.4 | 3.6 | 4.6 | 4.0 | 3.79 |
| 16 | Residential | Energy management of appliances | 3.5 | 3.5 | 3.5 | 4.3 | 4.3 | 3.75 |
| 17 | Waste | Waste prevention - 5% | 3.7 | 3.8 | 3.3 | 4.2 | 4.4 | 3.72 |
| 18 | Waste | Recycling program – 20% | 3.8 | 4.2 | 3.1 | 4.2 | 4.4 | 3.69 |
| 19 | Residential | Television (EE Standard 2) | 4.3 | 3.8 | 3.9 | 2.9 | 2.9 | 3.69 |
| 20 | Residential | Television (EE Standard 1) | 4.3 | 3.8 | 3.9 | 2.9 | 2.9 | 3.69 |
| 21 | Transport | Mandatory fuel efficiency labelling | 3.6 | 4.1 | 3.2 | 4.2 | 4.2 | 3.65 |
| 22 | Waste | Home composting - 15% yield | 3.5 | 3.5 | 3.4 | 4.3 | 4.4 | 3.64 |
| 23 | Public and commercial | Setting LED target of 100% by 2030 (commercial buildings) | 3.4 | 3.9 | 2.9 | 4.1 | 4.4 | 3.64 |
| 24 | Public and commercial | Green Building Standard 2 | 3.6 | 4.3 | 2.4 | 4.4 | 4.7 | 3.64 |
| 25 | Waste | Home composting - 30% yield | 3.6 | 3.6 | 3.1 | 4.5 | 4.5 | 3.62 |
| 26 | Transport | Street metering expansion | 3.9 | 4.0 | 3.0 | 4.1 | 4.1 | 3.62 |
| 27 | Waste | Centralised composting | 3.4 | 3.6 | 3.1 | 4.5 | 4.6 | 3.61 |
| 28 | Waste | Recycling program - 40% | 3.2 | 3.8 | 3.0 | 4.6 | 4.9 | 3.60 |
| 29 | Transport | Increase in CNG bus service - 20% | 3.3 | 4.3 | 3.2 | 3.8 | 4.0 | 3.60 |
| 30 | Waste | Hybrid waste collection retrofit | 3.5 | 4.4 | 2.8 | 4.2 | 4.3 | 3.59 |
| 31 | Transport | Teleworking | 3.1 | 4.1 | 3.4 | 4.1 | 4.1 | 3.58 |
| 32 | Residential | Setting LED target of 50% | 3.6 | 3.4 | 3.3 | 4.2 | 4.0 | 3.57 |
| 33 | Waste | LFG flaring | 3.4 | 3.7 | 3.3 | 3.8 | 4.1 | 3.55 |
| 34 | Transport | Bike sharing | 3.9 | 4.2 | 4.1 | 4.7 | 4.7 | 4.17 |



## Appendix F:

*continued*

| Rank | Sector | Measure | Political acceptability | Public acceptability | Capacities for implementation | Impact on human development | Impact on environment | Weighted score |
|---|---|---|---|---|---|---|---|---|
| 35 | Public and commercial | Green Building Standard 1 | 3.6 | 4.2 | 2.4 | 4.1 | 4.5 | 3.53 |
| 36 | Public and commercial | Double glazed reflective glass plus polystyrene insulation (public buildings) | 3.6 | 4.2 | 2.4 | 4.1 | 4.5 | 3.53 |
| 37 | Public and commercial | Double glazed reflective glass plus polystyrene insulation (commercial buildings) | 3.6 | 4.2 | 2.4 | 4.1 | 4.5 | 3.53 |
| 38 | Waste | Waste prevention – 10% | 3.3 | 3.3 | 3.0 | 4.5 | 4.6 | 3.51 |
| 39 | Transport | Converting taxis to CNG by 2030 | 3.6 | 4.4 | 2.9 | 4.0 | 4.4 | 3.49 |
| 40 | Transport | Converting existing bus fleet to CNG by 2030 | 3.1 | 4.4 | 2.9 | 4.2 | 4.4 | 3.49 |
| 41 | Public and commercial | Setting LED target of 100% by 2030 (public buildings) | 3.2 | 4.1 | 2.6 | 4.0 | 4.3 | 3.49 |
| 42 | Waste | Energy from waste (electricity) | 3.4 | 4.3 | 2.6 | 4.2 | 4.2 | 3.47 |
| 43 | Residential | Washing machine (EE Standard 2) | 3.6 | 3.8 | 3.4 | 3.1 | 3.1 | 3.42 |
| 44 | Residential | Washing machine (EE Standard 1) | 3.6 | 3.8 | 3.4 | 3.1 | 3.1 | 3.42 |
| 45 | Transport | Increase in hybrid bus service - 40% | 2.8 | 4.4 | 2.9 | 4.2 | 4.3 | 3.41 |
| 46 | Residential | Passive cooling – evaporative cooling via porous roofs | 3.0 | 3.9 | 2.3 | 4.8 | 4.8 | 3.39 |
| 47 | Residential | Passive cooling – thermal insulation | 3.0 | 3.9 | 2.3 | 4.8 | 4.8 | 3.39 |
| 48 | Residential | Solar-assisted electric shower | 2.8 | 4.0 | 2.8 | 4.3 | 4.3 | 3.38 |
| 49 | Transport | 50% of vehicles converted to CNG by 2030 | 3.1 | 4.2 | 2.9 | 3.9 | 4.3 | 3.37 |
| 50 | Transport | Subsidy for scrapping old vehicles - hybrid voucher | 2.5 | 3.9 | 3.0 | 4.3 | 4.3 | 3.34 |
| 51 | Residential | HIT solar PV panel | 3.2 | 3.8 | 2.4 | 4.0 | 4.8 | 3.31 |
| 52 | Residential | a-Si solar PV panel | 3.2 | 3.8 | 2.4 | 4.0 | 4.8 | 3.31 |
| 53 | Transport | Increase in CNG bus service - 40% | 3.1 | 4.0 | 2.5 | 4.1 | 4.4 | 3.27 |
| 54 | Transport | Converting existing bus fleet to hybrids by 2030 | 2.8 | 3.8 | 2.9 | 3.9 | 4.2 | 3.25 |
| 55 | Transport | Converting existing bus fleet to biodiesel by 2030 | 3.2 | 3.7 | 2.9 | 3.8 | 3.8 | 3.25 |
| 56 | Public and commercial | Elevators and escalators (EE Standard 2) | 3.2 | 4.3 | 2.4 | 3.5 | 3.6 | 3.23 |
| 57 | Public and commercial | Elevators and escalators (EE Standard 1) | 3.2 | 4.3 | 2.4 | 3.5 | 3.6 | 3.23 |
| 58 | Transport | Subsidy for scrapping old vehicles – cash payment | 2.4 | 3.8 | 3.0 | 3.8 | 3.7 | 3.20 |
| 59 | Waste | Energy from waste (combined heat and power) | 3.3 | 3.8 | 2.3 | 4.0 | 4.2 | 3.19 |
| 60 | Public and commercial | HIT solar PV panels | 2.7 | 3.6 | 2.3 | 4.0 | 4.4 | 3.19 |
| 61 | Residential | Passive cooling – high albedo | 2.8 | 3.5 | 2.1 | 4.8 | 4.8 | 3.16 |
| 62 | Residential | Passive cooling - high albedo and evaporation via porous roofs | 2.8 | 3.5 | 2.1 | 4.8 | 4.8 | 3.16 |
| 63 | Public and commercial | a-Si solar PV panel | 2.8 | 3.5 | 2.4 | 3.7 | 4.2 | 3.14 |
| 64 | Transport | EU carbon emissions vehicle standards | 2.7 | 3.6 | 2.4 | 3.9 | 4.0 | 2.96 |
| 65 | Public and commercial | Turning off indoor lights for an additional hour per day | 2.5 | 2.2 | 2.4 | 3.0 | 3.5 | 2.69 |
| 66 | Waste | Incineration | 2.6 | 2.5 | 3.0 | 2.4 | 2.2 | 2.63 |
| 67 | Residential | Turning off lights for one additional hour per day | 2.4 | 2.0 | 2.1 | 3.3 | 4.0 | 2.60 |

# The Climate Smart Cities Programme
## www.climatesmartcities.org

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The intellectual property rights for the methodology and approach applied in this report are retained by the University of Leeds. The University of Leeds does not accept any responsibility for the ways in which the report or the data are used.


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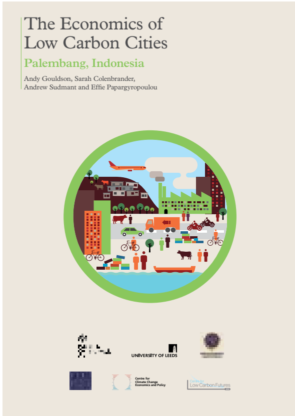
Kolkata, India

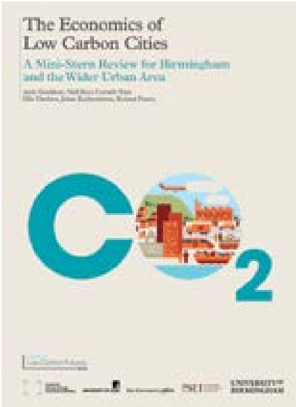

Lima-Callao, Peru



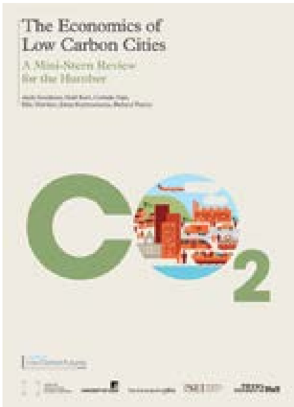

Palembang, Indonesia


Johor Bahru, Malaysia

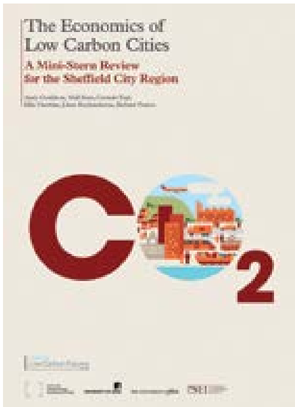

Leeds City Region




Birmingham and the Wider Urban Area




The Humber

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