# The Economics of Low Carbon Cities

## Kigali, Rwanda

Andy Gouldson, Sarah Colenbrander, Andrew Sudmant, Natasha Chilundika, Herman Musahara and Lea de Melo

IGC International Growth Centre

UNIVERSITY OF LEEDS

OSSREA

# The Economics of Low Carbon Cities

## Kigali, Rwanda

## Today

Today 10.1% of city-scale GDP – USD 301 million – leaves the local economy every year through payment of the energy bill.


10.1% of GVA leaks out of the economy

## Tomorrow

Investing 0.6% of GVA p.a. leads to...

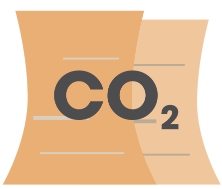
Leads to...

0.6% of GDP or $17 million could be profitably invested, every year for ten years, to exploit economically attractive energy efficiency and low carbon opportunities.

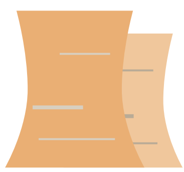
- **Energy**
  reductions in the energy bill of 1.5% of GDP p.a. or savings of $203m in 2032
- **Financial Viability**
  5.3 years for measures to pay for themselves
- **Employment**
  new jobs and skills in low carbon goods and services
- **Wider economic benefits**
  reduced energy expenditure, improved energy security, extra GDP
- **Wider social benefits**
  improved energy access, better indoor air quality, less congestion

### Potential to reduce greenhouse emissions relative to business as usual

Business as usual in 2032

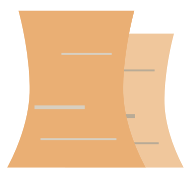



39.0% GHG reduction



Through exploitation of profitable options

42.5% GHG reduction



Through exploitation of no net cost options

# Figures





# Table of Contents

# Tables and Appendices

## Tables



## Appendices





# Executive Summary

## Introduction

**What is the best way to shift a city to a 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 Kigali, and to use it to examine whether there is an economic case to justify pursuing a low-carbon development path and to mobilise large-scale investment 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 in the housing, commercial and public buildings, transport and waste sectors within Kigali.

## Our Approach

We start the analysis by collecting data on levels and composition of energy use in Kigali. We do this for a range of different sectors including the electricity, housing, commercial, transport, industry and waste sectors. Primary data was provided by a number of government agencies including the Ministry of Infrastructure (MINIFRA), the Rwanda Transport Development Authority (RTDA), and Rwanda Energy Group (REG).

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. These historical trends inform 'business as usual' baselines that project future levels and forms of energy supply and demand, as well as future energy bills and carbon emissions, to 2032.

Based on extensive literature reviews and stakeholder consultations, we compile lists of the low-carbon measures that could potentially be applied in residential, commercial and public buildings, transport, electricity and waste sectors in the city. The industry sector was excluded at this stage due to the lack of data. 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 Kigali in the period to 2032. 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. The results are presented in 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.

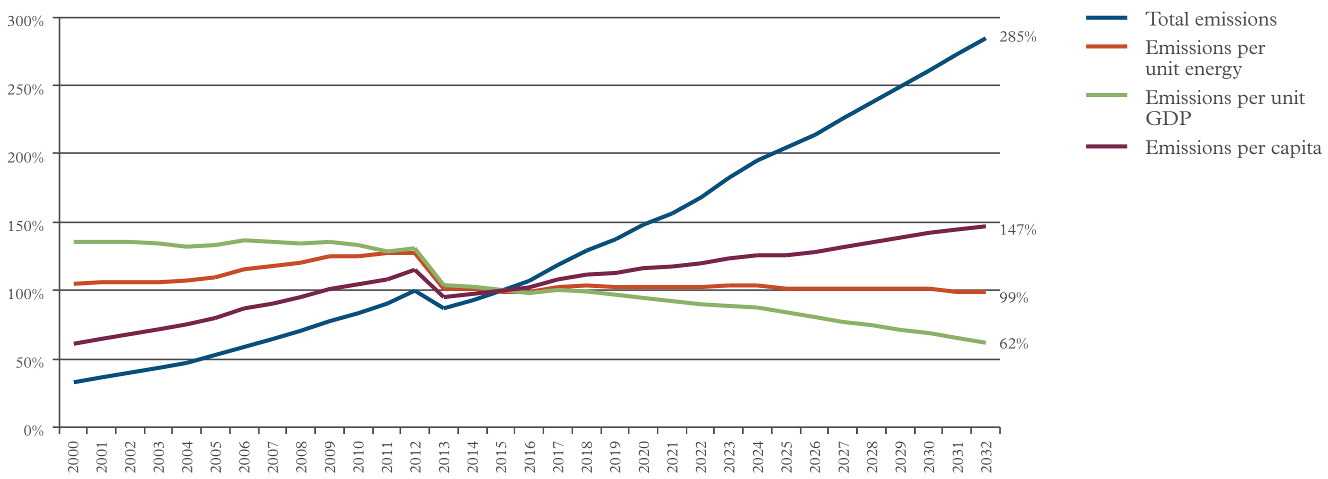
We draw together the results from our assessment and the expert review to determine the potential impact of the combined measures across the different sectors of the city as a whole. This allows us to understand the scale of the development opportunity, the associated investment needs and paybacks, as well as impacts on energy supply and demand, energy bills and carbon emissions in the different sectors in the city.

## The Economic Case for Low-Carbon Investment

We estimate that Kigali's GDP was RWF 2.0 trillion (USD 3.0 billion) in 2015, and if recent trends continue we forecast that GDP will grow to RWF 9.5 trillion (USD 13.7 billion) by 2032. We also find that the total energy bill for Kigali in 2015 was RWF 206.1 billion (USD 301.0 million), meaning that 10.1% of Kigali's GDP is spent on energy.

We predict that a continuation of business as usual trends in the period to 2032 would see total energy use in Kigali rising by 187.0% from 2015 levels to 2032 and we forecast that the total energy bill for the city will increase by 249.7% from 2015 levels to RWF 720.8 billion (USD 1.1 billion) in 2032. With continued economic growth, this would mean that energy bills will consume an estimated 7.7% of city-scale GDP in 2032. We also predict that, in a business as usual scenario, total carbon emissions from Kigali will increase by 184.9% from 2015 levels by 2032.

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

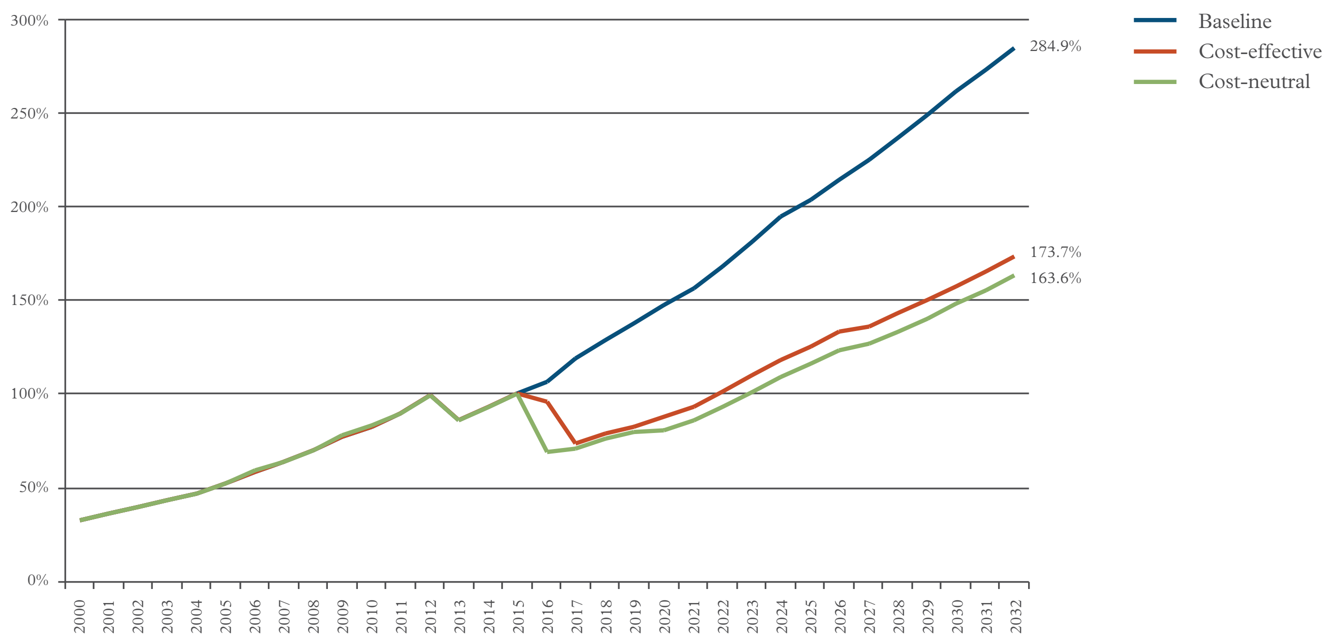



After examining the potential costs and benefits of the wide range of energy efficiency, renewable energy and other low-carbon measures that could be deployed across different sectors in the city, we find that – compared to business as usual trends – the city of Kigali could reduce its carbon emissions by 2032 by:

– 39.0% through cost-effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of RWF 630.6 billion (USD 920.7 million), generating annual savings of RWF 118.6 billion (USD 173.2 million), paying back the investment in 5.3 years and generating annual savings for the lifetime of the measures.

– 42.6% through cost-neutral investments that could be paid for by re-investing the income generated from the cost-effective measures. This would require net investment of RWF 1.0 trillion (USD 1.5 billion), generating annual savings of RWF 138.8 billion (USD 202.6 million), paying back the investment in 7.5 years and generating annual savings for the lifetime of the measures.

**Figure 2: Emissions from Kigali under three different investment scenarios, indexed against 2015 emissions, between 2000 and 2032.**



We find that the waste sector contains 74.1% of the cost-effective emissions savings potential in Kigali, with the remaining potential being distributed among the domestic sector (5.8%), the commercial and public sector (1.1%), the electricity sector (5.6%) and the transport sector (13.4%). The step change in the cost-effective and cost-neutral scenarios between 2015 and 2018 reflects large-scale investments coming online in the transport and waste sectors. The waste sector has particularly substantial mitigation potential for two reasons. Firstly, like many other cities in Least Developed Countries, waste is responsible for a much larger share of emissions than in higher income contexts as urban residents consume much less energy than their counterparts in middle and high-income cities. Secondly, the low-carbon measures in the waste sector generate electricity, which displaces high-carbon electricity from the grid and thereby avoids emissions from burning fossil fuels for this purpose.

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 because of ongoing growth – even if that growth is more energy-efficient and less carbon-intensive than before these investments were made. If the City of Kigali exploited all of the cost-effective options, emissions would be 73.7% above 2015 levels by 2032. However, these measures would also save RWF 138.8 billion (USD 202.6 million) in energy expenditure each year, thereby reducing the energy bill in 2032 from a projected 7.7% of GDP to 6.2%. With the exploitation of all cost-neutral measures, the city's emissions rise by only 63.6% above 2015 levels instead of by 184.9%.

This investment in cost-effective and cost-neutral options can buy cities much needed time to search for, adopt and lock in permanent reductions in emissions. We can measure this with the Time to Reach BAU Emission Levels (TREBLE) point, which compares the time taken in years for emissions with investment in low-carbon measures to reach the level that would have been realized without such investment under the BAU scenario in a reference year (Gouldson et al., 2015). If all cost-effective options are implemented, the TREBLE point relative to 2032 in Kigali will be 13.4 years. If all cost-neutral measures are implemented, emissions will only reach their 2032 business as usual level in 14.3 years. In other words, economically neutral levels of investment in climate mitigation can keep emissions in Kigali below business as usual trends for more than a decade 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 promote a more sustainable and climate-friendly form of development in Kigali, which would also improve the economic competitiveness of the city while reducing energy bills for urban households, businesses and government. 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.

While we hope that Kigali can use these findings to inform future development plans, we recognise that the presence of such opportunities does not mean that they will necessarily be realised. 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 Kigali to secure the investments and develop the delivery models needed for ambitious climate action. Some of the low-carbon measures could be commercially attractive while 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.

We stress that economic considerations alone should not shape the transition to a low-carbon development model in urban Rwanda. Decision-makers should also consider the issues relating to the equity, inclusivity and broader sustainability of each measure. 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 climate action helps to mobilise political will for and public interest in ambitious climate action in Kigali.

# 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 urban areas, 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, the economic and social activity that takes place in cities consumes 67-76% of all energy, and is 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., 2015). 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 countries experiencing rapid population and economic growth, 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 climate 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 Kigali, 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. The report reviews the cost and carbon-effectiveness of a wide range of supply and demand measures that could be applied to energy use in Kigali. 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 lower-carbon development path.

## Rwanda

Rwanda is a small, landlocked country in East Africa. With a population of 12 million people in an area of 26,338 km2, it is the most densely populated country in Africa. Moreover, the population density is likely to increase: Rwanda's population grew by 2.9% in 2014 and is expected to more than double from 12 million today to 26 million by 2050 (Republic of Rwanda, 2011).

The Rwandan economy achieved real GDP growth of about 9% per annum between 2000 and 2014 (World Bank, 2014). In the past decade, this growth has translated effectively into poverty reduction, largely through a doubling in household-level agricultural production (World Bank, 2014). Despite these impressive achievements, the incidence of poverty remains high with 45% of the population living below the national poverty line in 2011 (World Bank, 2014).

The scale of the development challenge is evident from the low levels of access to modern energy and clean water. Currently, 25.8% of Rwandans do not have access to an improved water source, while 83.2% do not have access to electricity even for lighting purposes (NISR, 2014). Biomass still accounts for 85% of national energy consumption, followed by petroleum at 11% and electricity at 4% (AfDB, 2013). The government has set increasingly ambitious targets to improve access to both water and electricity. The original version of the national strategy document, Vision 2020, established two policy goals that were subsequently revised upwards. Originally, Vision 2020 outlined the policy goal of providing access to electricity to 35% of the population and access to improved sanitation to 60% of the population by 2020. These targets were revised upwards in 2012, to 70% and 100% respectively (MINECOFIN, 2012).

While Rwanda's economic growth is rapid, it is also precarious. The country remains highly dependent on rain-fed subsistence agriculture for rural livelihoods, on exports of tea and coffee for foreign exchange earnings, and on hydropower for half of domestic electricity generation (Republic of Rwanda, 2011; AfDB, 2013). Future economic development and poverty alleviation therefore remains vulnerable to climate variability and climate change.

The Government of Rwanda has committed to mainstreaming environmental sustainability and climate resilience into both productive and social sectors, as outlined in the National Strategy for Climate Change and Low Carbon Development (Republic of Rwanda, 2011). This document recognises that even where substantial co-benefits to climate action are available, action is likely to be constrained by lack of finance and capacities. To remedy this, Rwanda has established an innovative basket fund – the National Environment and Climate Change Fund (FONERWA) – to finance climate actions, and has built strategic public-private relationships to finance climate action and build relevant capacities (Nash and Ngabitsinze, 2014). The National Strategy has also informed the Economic Development and Poverty Reduction Strategy 2013-2018 (Republic of Rwanda, 2013), which guides national planning and budgeting. The Rwandan Environmental Management Authority has been designated the lead authority on climate change, and is mandated to coordinate national action on climate change (Fisher et al., 2014).

Rwanda's leadership on climate change is particularly impressive considering that the country has among the lowest levels of per capita emissions in the world. Rwandans are estimated to emit 0.1t$CO_2$-e per person from energy consumption and 0.6t$CO_2$-e per person when emissions from land use change are incorporated (Republic of Rwanda, 2011). For reference, the global average is 4.6t$CO_2$-e from energy consumption (EIA, 2012), while people in OECD countries emit an average of 12.7t$CO_2$-e per capita (OECD, 2015).

## Kigali

Rwanda remains predominately rural, with only 15% of the population living in urban areas. With a population of 1.1 million people, the capital city – Kigali – accommodates 10% of the population and is easily the largest city in Rwanda (NISR, 2013). Located in the heart of the country, Kigali is comprised of three districts: Gasabo in the North, Nyarugenge in the West and Kicukiro in the South (KCC, 2011). A host of successful government programs, including a plastic bag ban, improved public waste disposal and beautification initiatives, have earned Kigali a reputation as one of the world's cleanest cities (UN-Habitat 2008). In recognition of these achievements the city was awarded the UN-Habitat Scroll of Honour Awards in 2008.

The population of the city doubled between 2000 and 2010. This rapid urban expansion, coupled with rising affluence and vehicle ownership, has put public services and infrastructure under increasing stress. Between 2005 and 2011 the stock of private cars more than doubled, leading to rising congestion (NISR, 2013), while dependence on wood and charcoal fuel has led to high levels of particulate air pollution in Kigali and the emergence of a 'heat island' effect in the city (Henninger 2013). Over the period between 2000 and 2015, emissions from transport rose at the fastest rate of any sector (8.9%), followed by the buildings sector (8.1%) and the waste sector (6.4%). Critically, expenditure on energy rose more than tenfold within fifteen years.

Looking forward, continued economic growth offers the hope that Kigali will build upon its human development gains. More than 87% of Kigali residents are below 40, and are therefore either a member of, or are soon to join, the workforce. As with cities around the world, population density permits more efficient provision of basic services and creates opportunities for local businesses to collaborate and innovate. At the same time, poorly managed urbanisation can lead to urban slums and their associated economic, social and environmental problems.

Advancing climate change may add to this challenge. Rising temperatures are anticipated to increase the risk of malaria transmission in Rwanda (Ermert et al., 2013). Flooding and drought – and their socioeconomic impacts – will be more frequent, less predictable, and have larger impacts on public health, infrastructure and food security (Byamukama, 2011). Rwanda already struggles with climate variability: in the recent past, major flooding events occurred in 1997 and 2006-2009, and major droughts occurred in 1999 and 2005 (Downing et al., 2009).

Two 'master plans' have been developed to conceptualise future growth in Kigali. The first, completed by Oz Architecture (2007), emphasises a need for graded density: lower density in suburban areas (40 residents per hectare), and higher density in the central business district (250 residents per hectare). The report also emphasises the need for walkable communities and urban development around existing transit nodes to maximise connectivity. The Kigali Master Plan 2013, developed by Surbana International Consultants, also emphasises the need for urban density, for example by requiring a minimum of 16 storeys for new developments, and the need for multimodal transit system based around existing transit nodes. Surbana International Consultants (2013) have also introduced a long-term plan for a bus rapid transit (BRT) system. We hope that this research helps to inform urban planning in Kigali, ensuring that the Rwandan capital can support the country's low-carbon development strategy.



## Aims and Objectives

What is the best way for a city to pursue low-carbon development path? It is important to demonstrate the local benefits of climate action in order to mobilise political commitment and engage a broad range of actors. When a country faces pressing development needs, it is also necessary to identify interventions that do not entail significant opportunity costs and may ideally free up resources for more socially and economically productive investment. Despite Rwanda's commitment to climate action, decision-makers are hindered by the absence of a credible and locally appropriate evidence base to guide policy and investment.

This study aims to provide such an evidence base for Kigali, 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 Kigali, 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.

This research 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 options, 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

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

For each of these sectors, and for the city as a whole, we examine the influence of recent trends in, for example, economic growth, population growth, consumer behaviour and energy efficiency. We then develop 'business as usual' baselines based on the continuation of these trends and the impact of planned investments through to 2032. The target year of 2032 was chosen in consultation with stakeholders based on national and city-level plans. National goals and plans are currently structured around Vision 2020, but a five year period does not offer an adequate timeframe for significant climate action or meaningful economic returns. The year 2032 was therefore selected so that the findings in this report align with the Kigali Transportation Master Plan (City of Kigali, 2013a) and can inform the implementation of longer-term, city-scale master plans (for example, City of Kigali, 2013b).

These baselines allow us to predict future levels and forms of energy supply and demand, as well as future capital costs, household bills and carbon footprints. We compare all future activities against these baselines. The baselines are reviewed by stakeholder workshops including representatives of government bodies, industry and research institutions. The list of participants is included in Appendix A. More 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 electricity, commercial and public, residential, transport and waste sectors in the city.

We include both technological and behavioural measures in our analysis. The long lists of all potential measures are drawn from extensive literature reviews, and then we review these to remove any options that are not applicable in a Rwandan 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 determine the net present value of each measure on the shortlists, using a real interest discount rate of 5%. 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 increasing use of bicycles depends on the impact on modal share of other 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.

The options appraisals are then reviewed in stakeholder workshops to ensure that they are as realistic as possible. Lists of all of the measures considered in the analysis are presented in Tables 1 and 2. A detailed explanation of the data sources and assumptions used during the options appraisal is presented in Appendix C.

**Table 1: Installed capacity by fuel type in 2032 under the different scenarios considered in the evaluation of the electricity sector (MW).**

| | Baseline | Thermal Scenario | JICA low cost | Solar 1 | Solar 2 | Geothermal 1 | Geothermal 2 |
|---|---|---|---|---|---|---|---|
| Hydro | 285.15 | 113.15 | 293.15 | 285.15 | 190.15 | 190.15 | 173.15 |
| Solar | 10.75 | 10.75 | 10.75 | 60.75 | 260.75 | 10.75 | 10.75 |
| Peat | 145 | 195 | 145 | 145 | 145 | 145 | 95 |
| Natural gas | 203.6 | 253.6 | 278.6 | 203.6 | 203.6 | 128.6 | 128.6 |
| Diesel | 73.3 | 73.3 | 313.75 | 73.3 | 69.3 | 45.3 | 45.3 |
| Geothermal | 0 | 0 | 0 | 0 | 0 | 100 | 200 |
| Imports | 493.5 | 493.5 | 3.5 | 493.5 | 493.5 | 493.5 | 493.5 |

**Table 2: Lists of the low-carbon measures considered in the evaluation of the commercial and public, residential, transport and waste sectors.**

| Sector | Measures |
|---|---|
| **Commercial and public buildings** | Replacing incandescent bulbs with compact fluorescent (CFL) bulbs; replacing incandescent bulbs with light emitting diodes (LEDs); replacing CFL bulbs with LEDs; building energy efficiency standards; solar panels (1.5kWp and 2.5kWp models); solar water heaters (300L models); street lighting: replacing sodium high pressure bulbs with LEDs. |
| **Residential buildings** | Replacing incandescent bulbs with CFL bulbs; replacing incandescent bulbs with LEDs; buildings energy efficiency standards – training workshops; improved cookstoves (SAVE80 and JICO models); replacing charcoal cookstoves with LPG stoves; solar home systems (200W, 120W, 80W and 30W models); solar water heaters (200L and 300L models). |
| **Transport** | Bus network expansion; bus network expansion with hybrid vehicles; Bus Rapid Transport (BRT) system – Central Business District (CBD) to Rususoro; BRT system – CBD to Gahanga; cycle lanes; electric motorbikes; Euro IV vehicle standards; import age restrictions (<15 years and <10 years); parking metres in the CBD. |
| **Waste** | Anaerobic digestion; biogasification; home composting; landfill gas flaring; landfill gas utilisation; recycling; centralised (windrow) composting. |



## Assessment of the Scope for Deployment

We evaluate the potential scope for deploying each measure in Kigali in the period to 2032. 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 a measure to reduce emissions from a particular waste stream.

Based on stakeholder consultations, we develop realistic rates of deployment based on readily achievable levels of uptake. These assessments take into account the life spans 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.

# Chapter 3. The Key Findings

### The Impacts of Business as Usual Trends

Business-as-usual trends in Kigali show a gradual decoupling of energy use and economic output over the period 2000 to 2032. Population growth in Kigali and substantial increases in per capita demand will lead total energy consumption to rise 187.0%, from 2.1 TWh in 2015 to 6.1 TWh in 2032.

The electricity supply to Kigali has been growing rapidly. It has also been increasing in carbon intensity as diesel, peat and natural gas generation are added to the grid. Electricity prices are currently relatively high, compared to regional and international prices, and expected to remain so in the short-term while the electricity grid undergoes significant capital investment. However, these investments will underpin declining prices in the longer term. We therefore assume a modest 2% increase in real energy prices through 2032. This increase, combined with rising demand, is expected to lead to a more than tripling of energy expenditure in the city by 2032. Specifically, total expenditure on energy increases 249.7%, from RWF 206.1 billion (USD 301.0 million) to a forecast level of RWF 720.8 billion (USD 1.1 billion) in 2032.

Although the emissions intensity of electricity is expected to decline in the coming decade, rising demand for liquid fuels will prevent any significant change in the emissions intensity of energy consumed in Kigali through 2032. The rise in emissions is therefore driven by higher per capita energy consumption and a growing population. The emissions intensity of GDP, on the other hand, will decline slightly as less emission-intensive economic activities develop in the city, particularly the services sector. Over the period to 2032, per capita emissions are expected to increase by 59.9% and total emissions by 184.9%.

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

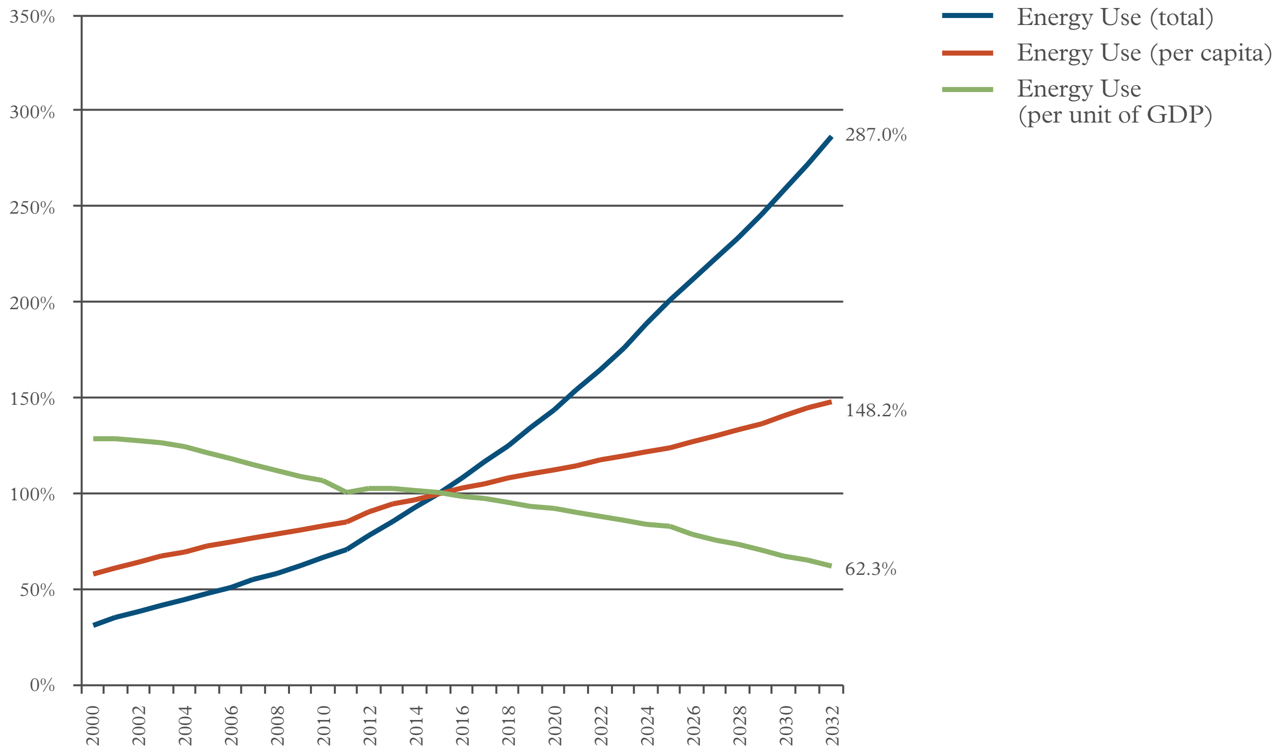
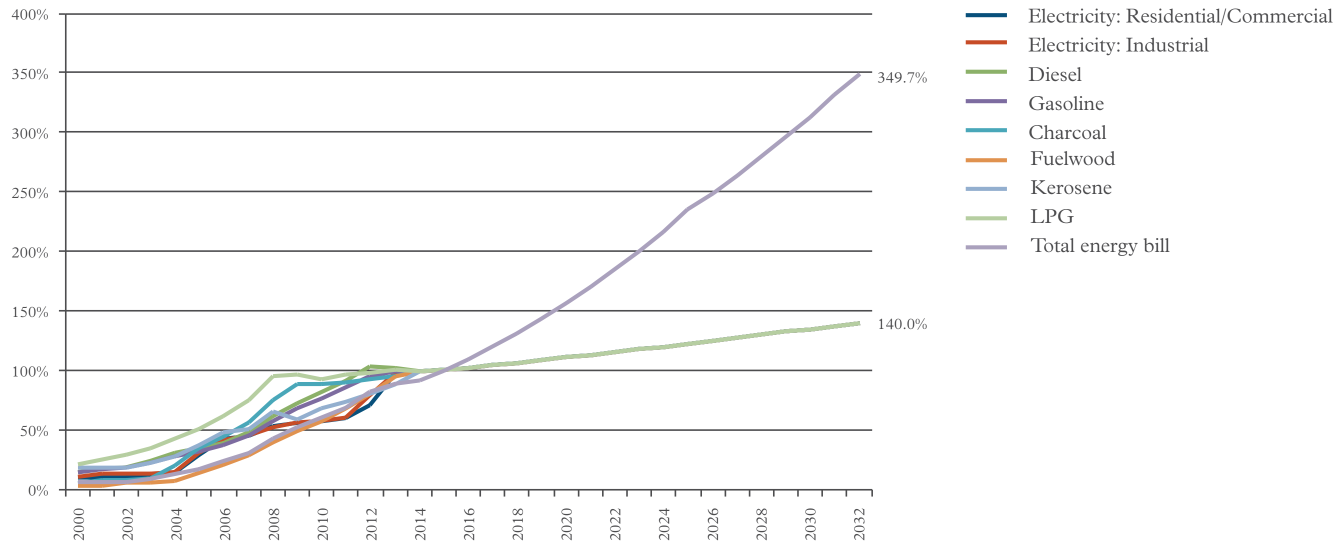


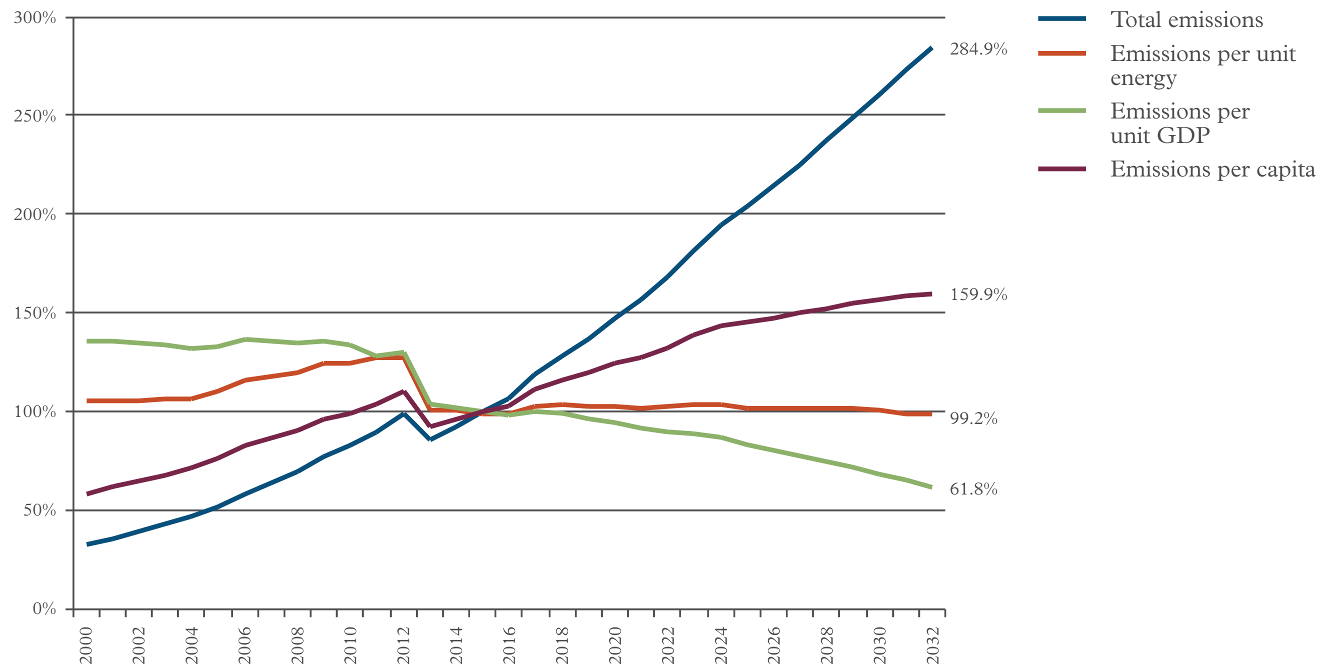



**Figure 4: Indexed energy prices and total energy bill. We use an annual price increase of 2% per annum for all energy prices, hence the forecast increase relative to 2015 prices is identical from 2016-2032.**

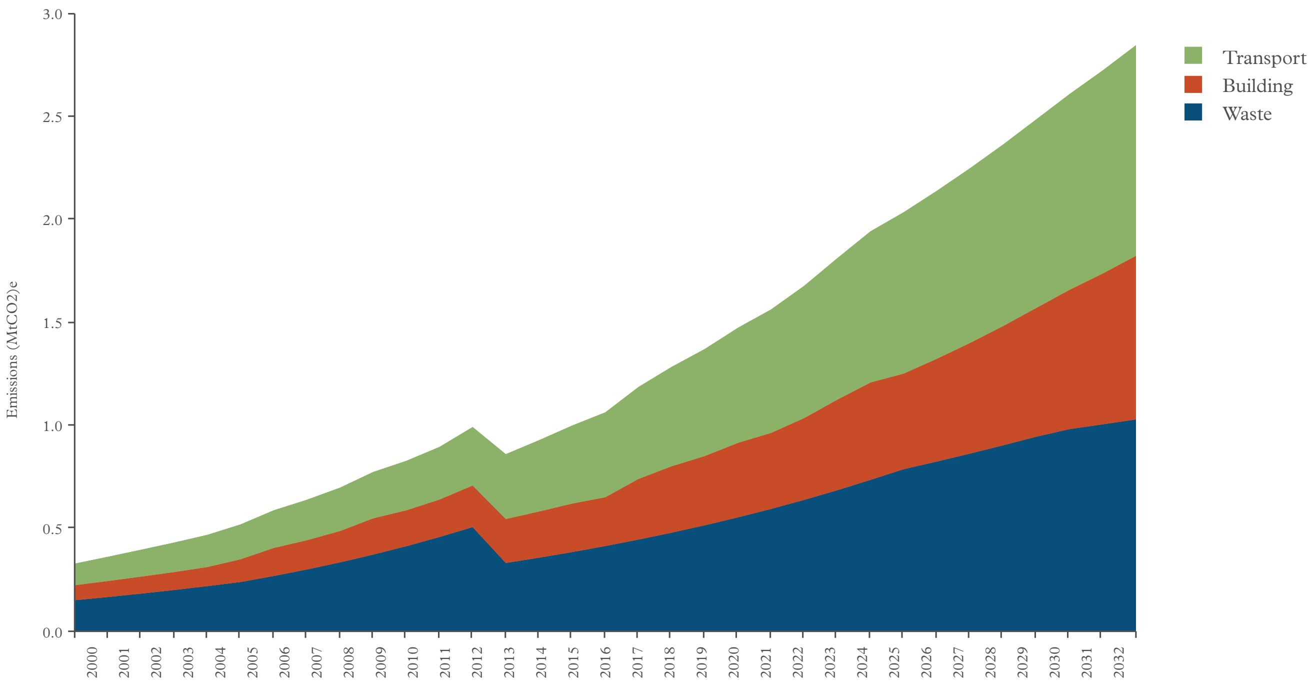



When combined with relatively stable levels of carbon emissions per unit of energy consumed, total carbon emissions from Kigali increase from 1.0 $MtCO_2$-e in 2015 to 2.8 $MtCO_2$-e in 2032.

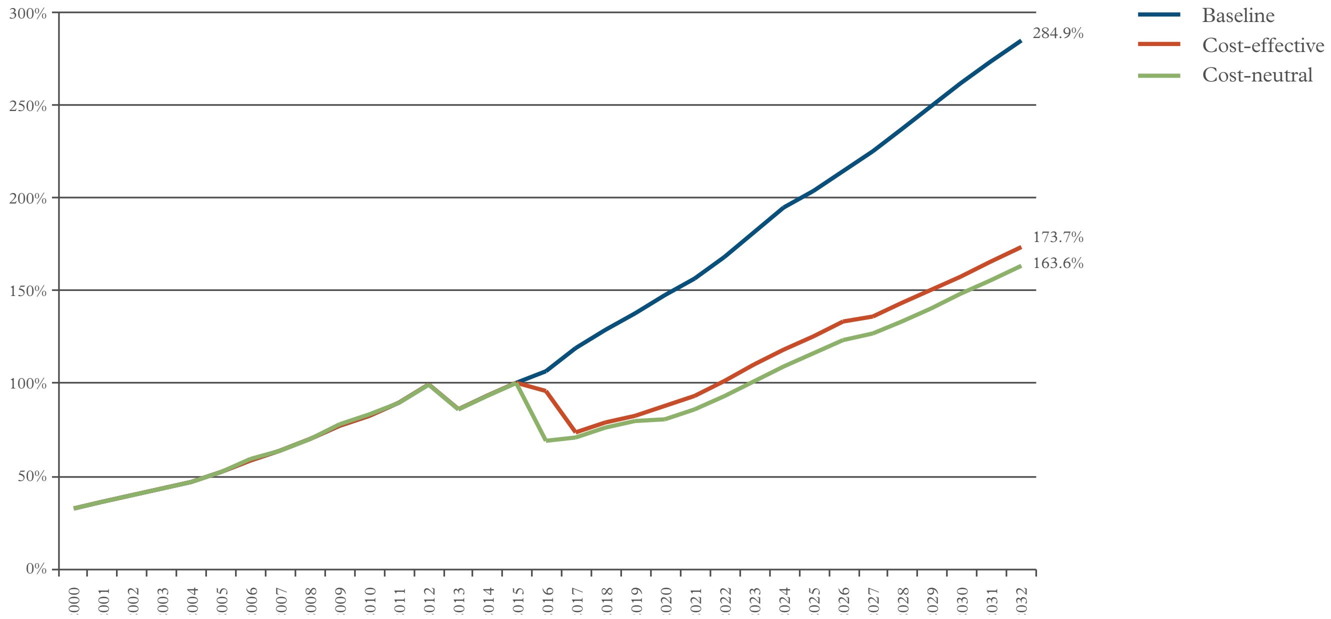
**Figure 5: Indexed emissions – total, per unit of energy, per unit of GDP and per capita.**



## Figure 6: GHG emissions by sector in Kigali, 2000 to 2032




## Figure 7: Emissions from Kigali under three different investment scenarios, indexed against 2015 emissions, between 2000 and 2032.




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

We find that – compared to 2015 – these 'business as usual' trends in carbon emissions could be reduced by:

- 39.0% through cost-effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of RWF 630.6 billion (USD 920.7 million), generating annual savings of RWF 118.6 billion (USD 173.2 million), paying back the investment in 5.3 years and generating annual savings for the lifetime of the measures.
- 42.6% through cost-neutral investments that could be paid for by re-investing the income generated from the cost-effective measures. This would require net investment of RWF 1.0 trillion (USD 1.5 billion), generating annual savings of RWF 138.8 billion (USD 202.6 million), paying back the investment in 7.5 years and generating annual savings for the lifetime of the measures.

We find that the waste sector contains 74.1% of the cost-effective emissions savings potential in Kigali, with the remaining potential being distributed among the domestic sector (5.8%), the commercial and public sector (1.1%), the electricity sector (5.6%) and the transport sector (13.4%). The step change in the cost-effective and cost-neutral scenarios between 2015 and 2018 reflects large-scale investments coming online in the transport and waste sectors. The waste sector contributes such a substantial share of city-scale mitigation potential for two reasons. Firstly, as in many other Least Developed Country cities, waste is responsible a much larger share of emissions than in higher income contexts, where energy consumption is greater. Secondly, the low-carbon measures in the waste sector generate electricity, which displaces high-carbon electricity from the grid and thereby avoids emissions from two sources.

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, emissions would be 73.7% above 2015 levels by 2032. These measures will also save RWF 138.8 billion (USD 202.6 million) in energy expenditure each year, thereby reducing the energy bill in 2032 from a projected 7.7% of GDP to 6.2%. With the exploitation of all cost-neutral measures, the city's emissions rise by only 63.6% above 2015 levels instead of 184.9%.

This investment in cost-effective and cost-neutral options can buy cities much needed time to lock in permanent reductions in emissions. We can measure this with the Time to Reach BAU Emission Levels (TREBLE) point, which compares the time taken in years for emissions with investment in low-carbon measures to reach the level that would have been realized without such investment under the BAU scenario in a reference year (Gouldson et al., 2015). If all cost-effective options are implemented, the TREBLE point relative to 2032 in Kigali will be 13.4 years. If all cost-neutral measures are implemented, emissions will only reach their 2032 business as usual level in 14.3 years. In other words, economically neutral levels of investment in climate mitigation can keep emissions in Kigali below business as usual levels for more than a decade 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.

# Sector Focus

## Chapter 4. Sector-Specific Results


# The Electricity Sector

### The Impacts of Business as Usual Trends

Rwanda has seen a substantial increase in domestic electricity production in recent years. Between 2000 and 2010, new diesel generation provided more than half of all electricity. However, Rwanda has an ambitious plan to diversify electricity resources over the coming decade as it expands electricity access and production. The country's national electrification plan is outlined in the Economic Development and Poverty Reduction Strategy 2013-2018 (Republic of Rwanda, 2013) and its sector development plan, outlined in the Electricity Development Strategy, both of which as designed to achieve targets established in the Vision 2020 strategy (MINECOFIN, 2012). Under these policy documents, natural gas is expected to be the largest source of domestic production by 2032, followed by hydro and peat-fired electricity generation. The rapid increase in electricity generation projected between 2014 and 2018 is based on planned investments (JICA, 2015).

The carbon intensity of electricity spiked between 2004 and 2014 due to a combination of new diesel generation and the impacts of a drought on hydroelectric generation. New generation from peat will further increase the emission factor in 2018, but methane generation, new domestic hydropower and a steady increase in electricity imports (predominately regional hydroelectricity) will reduce the carbon intensity of the Rwandan electricity grid through to 2032.

**Figure 8: Domestic electricity generation (MW) in Rwanda by fuel type, 2000 to 2032. Projections are based on planned investments.**

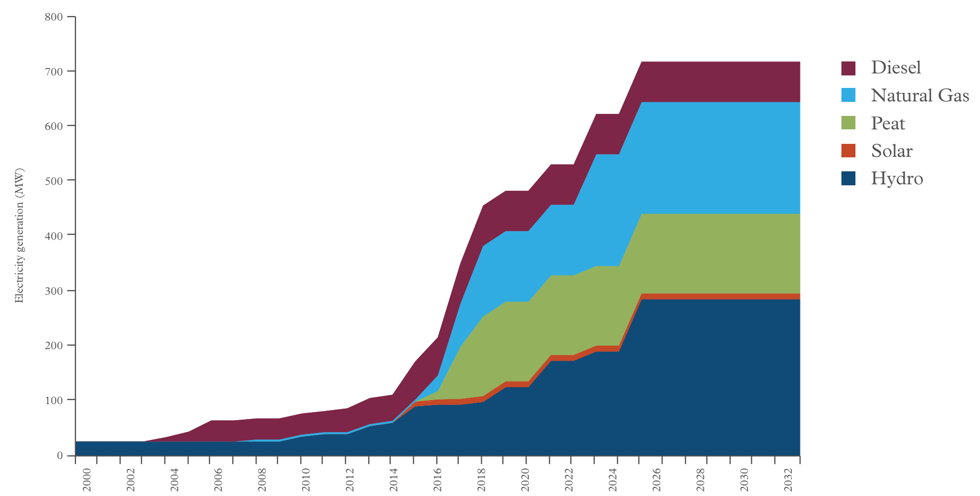
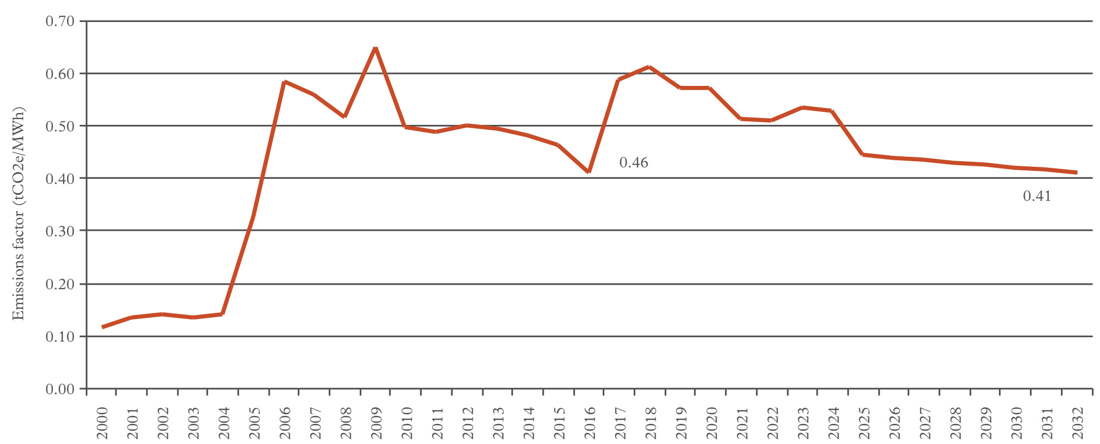



**Figure 9: Emissions factor of grid electricity in Rwanda, 2000 to 2032. This emissions factor includes the effects of imported electricity.**



## The Potential for Carbon Reduction – Investments and Returns

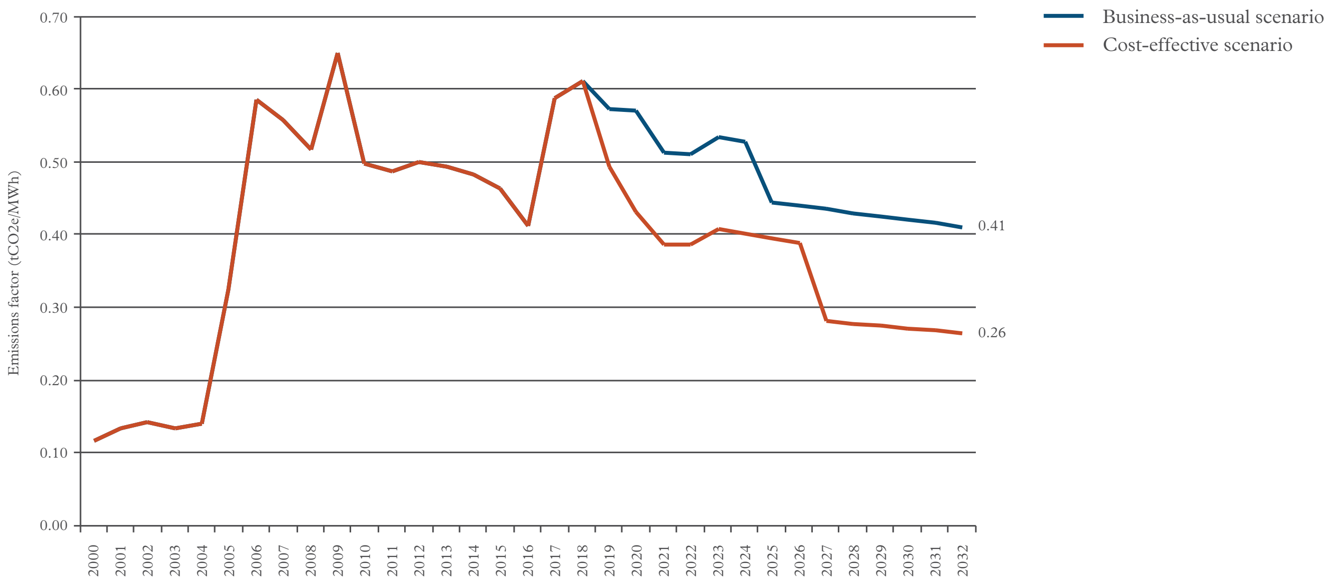
We find that significant reductions in capital expenditure, operating costs and emissions can be achieved through regional grid integration and the gradual exploitation of geothermal resources. This is evident when we compare the levelised cost of electricity in these scenarios to the levelised cost under business as usual. The levelised cost of electricity is the average total cost to build and operate electricity-generating infrastructure over its lifetime, divided by the total power output over the same period.

Under the baseline scenario RWF 2.2 trillion (USD 3.1 billion) will be spent on capital investment in the electricity sector through 2032 and carbon emissions in 2032 (per unit of electricity produced) will decline 11.4%. Under this scenario, the levelised cost of electricity will be RWF 109.8/kWh (USD 0.16/kWh).

Under a scenario where 100 MW of geothermal electricity generation and 493.5 MW of import capacity is operational by 2032 (scenario 'Geothermal 1'), capital costs will decline to RWF 1.9 trillion (USD 2.7 billion) and carbon emissions in 2032 will decline 18.0%. Under this scenario, the levelised cost of electricity will be RWF 93.0/kWh (USD 0.13/kWh).

Under a scenario where 200 MW of geothermal electricity generation and 493.5 MW of import capacity is operational by 2032 (scenario 'Geothermal 2') capital costs will decline to RWF 1.9 trillion (USD 2.8 billion) and carbon emissions in 2032 will decline 35.6%. Under this scenario, the levelised cost of electricity will be RWF 85.1 kWh (USD 0.12/kWh). Full details on the scenarios can be found in Appendix C.

**Figure 10: Emissions factor of electricity in Rwanda between 2000 and 2032 under two different investment scenarios.**






Cost effective

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 scenarios in the electricity sector.**

| Rank: | Measure: | USD/tCO2-e | RWF/tCO2-e |
|---|---|---|---|
| 1 | Geothermal 1 | -373 | -259,463 |
| 2 | Geothermal 2 | -369 | -256,294 |
| 3 | Solar 2 | 6,943 | 4,825,367 |
| 4 | Solar 1 | 9,244 | 6,424,301 |
| 5 | JICA low cost | -[1] | - |
| 6 | Thermal scenario | - | - |

**Table 4: League table of the carbon-effectiveness of low-carbon scenarios in the electricity sector.**

| Rank: | Measure: | ktCO2-e |
|---|---|---|
| 1 | Geothermal 2 | 10,137 |
| 2 | Geothermal 1 | 6,825 |
| 3 | Solar 1 | 147 |
| 4 | Solar 2 | 111 |
| 5 | JICA low cost | -118 |
| 6 | Thermal scenario | -5,061 |

1 Blank cells indicate that the scenario generates greater emissions than the baseline scenario.

2 The solid waste management strategic plan has lower estimates of per capita waste production (City of Kigali and BTC Rwanda, 2012).

# Sector Focus

## The Buildings Sector



# Sector Focus – The Buildings Sector

### The Impacts of Business as Usual Trends

8,500-10,000 dwelling units need to be constructed every year in Kigali in order to keep pace with rapid population growth (MININFRA, 2008). Despite urban planning initiatives, a large share of new housing developments is informal and takes place in unplanned areas. This type of growth has substantial implications for the social, economic and environmental quality of urbanisation. People living in informal settlements often have poor quality housing and limited access to clean water or grid electricity. Improving housing affordability and energy access is a much higher priority than improving energy efficiency in these contexts, although there are some opportunities to reduce energy expenditure by low-income households, particularly on charcoal and kerosene.

Kigali is enjoying rapid economic growth, led by the services sector. This is physically manifesting in the city through the large-scale construction of new office buildings, shopping malls and other commercial centres. Economic development is also fuelling the emergence of a middle class, which enjoys relatively reliable access to grid electricity compared with the rest of the country, and is responsible for much of the increase in electricity demand in the city. While Kigali is unlikely to experience the rapid growth in energy demand seen in cities with large heating and cooling demand, there will be significant opportunities to reduce energy bills over coming decades through lighting efficiency and the deployment of decentralised solar systems.

The location of new buildings is broadly guided by the Kigali Master Plan. The Ministry of Infrastructure is responsible for formulating housing policies (most notably the National Urban Housing Policy, published in 2008), which are implemented by government bodies such as the Rwanda Housing Agency.

Population and economic growth (concentrated in the services sector) is leading to soaring levels of energy consumption in residential, commercial and public buildings. In particular, the share of electricity and liquefied petroleum gas (LPG) will increase dramatically while the share of charcoal and fuelwood diminishes, although charcoal remains a major energy source. Energy consumption in this sector is projected to increase by 222.4%, from 2,390.1 TJ in 2015 to 7,704.8 TJ in 2032. When combined with increasing real energy prices (particularly rising electricity tariffs), energy expenditure by the buildings sector is projected to increase by 137.1%, from RWF 47.9 billion in 2015 to RWF 113.7 billion in 2032. Carbon emissions will increase by 237.0%, from 235.8 ktCO$_2$-e in 2015 to 794.7 ktCO$_2$-e in 2032.

Figure 11: Energy use by fuel type in the buildings sector in Kigali between 2000 and 2032.

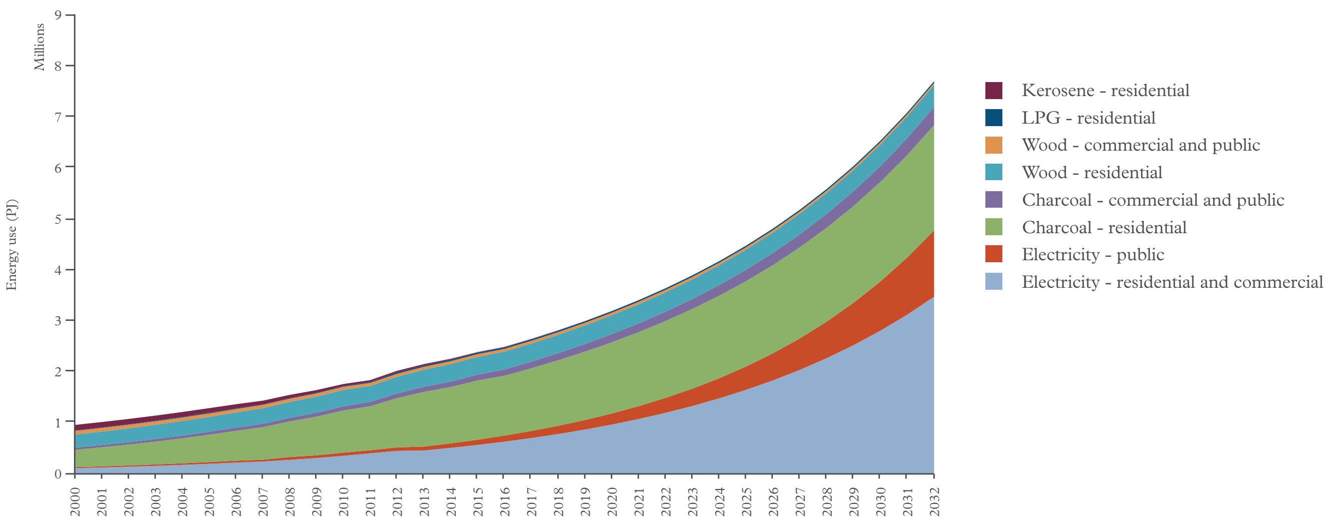
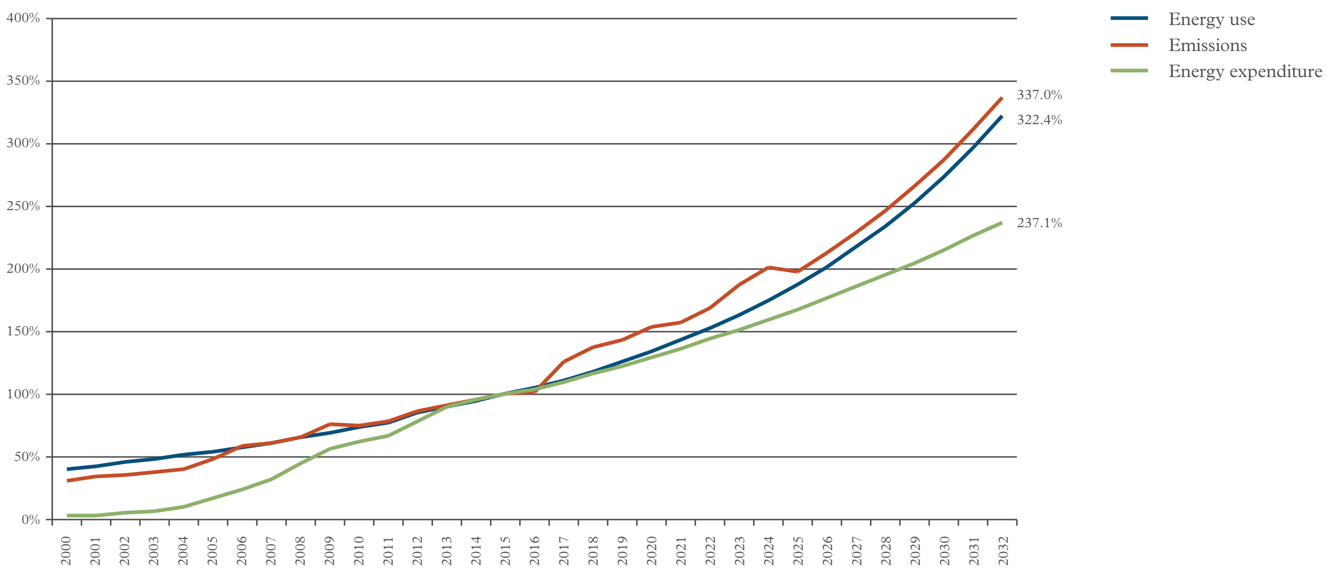



Figure 12: Indexed energy consumption, energy bills and emissions in the buildings sector in Kigali between 2000 and 2032.





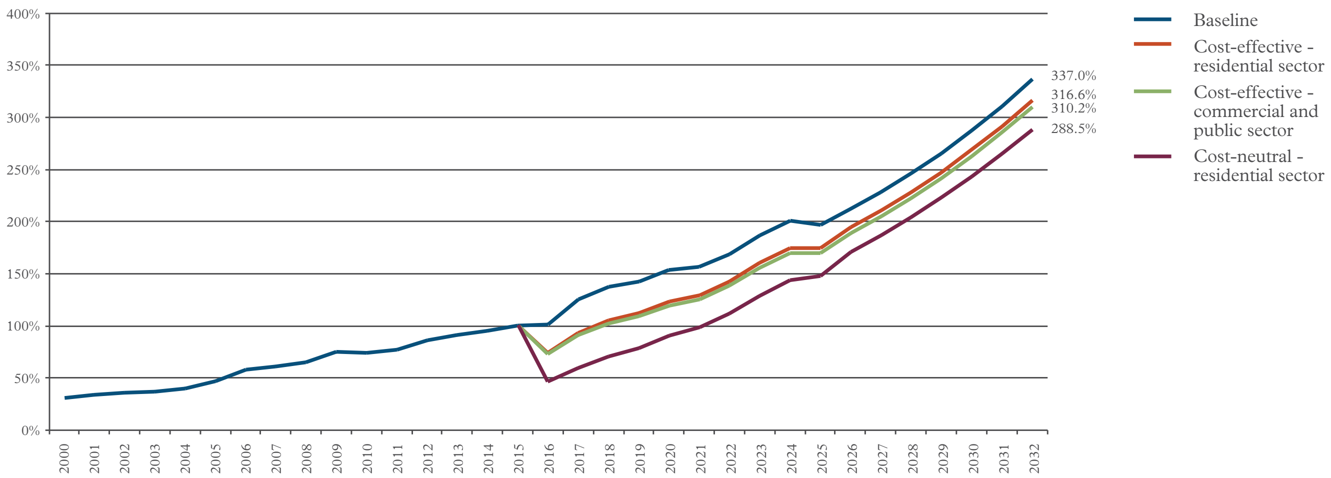

## The Potential for Carbon Reduction – Investments and Returns

We find that – compared to 2015 – these 'business as usual' trends in carbon emissions could be reduced by:

- 6.0% through cost-effective investments in the residential sector that would more than pay for themselves on commercial terms over their lifetime. This would require investment of RWF 77.7 billion (USD 113.4 million), generating annual savings of RWF 13.8 billion (USD 20.1 million), paying back the investment in 5.7 years and generating annual savings for the lifetime of the measures.
- 7.9% through cost-effective investments in the commercial and public sector that would more than pay for themselves on commercial terms over their lifetime. This would require investment of RWF 15.2 billion (USD 22.2 million), generating annual savings of RWF 6.8 billion (USD 9.9 million), paying back the investment in 2.2 years and generating annual savings for the lifetime of the measures.
- 14.3% through cost-neutral investments in the residential sector that could be paid for by re-investing the income generated from the cost-effective measures. This would require net investment of RWF 89.5 billion (USD 130.7 million) in the residential sector, generating annual savings of RWF 13.8 billion (USD 20.2 million), paying back the investment in 6.5 years and generating annual savings for the lifetime of the measures.

We did not identify any cost-neutral measures in the commercial and public sector.

Figure 13: Emissions from the buildings sector under four different investment scenarios, indexed against 2015 emissions, between 2000 and 2032.



Cost effective

Cost neutral

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

## Options Appraisal – Residential Sector

Table 5: League table of the cost-effectiveness of low-carbon measures in the residential sector.

| Rank: | Measure: | USD/tCO2-e | RWF/tCO2-e |
|---|---|---|---|
| 1 | Building energy efficiency – training workshops | -1,860 | -1,274,316 |
| 2 | Replacing kerosene lamps with solar lamps | -1,784 | -1,221,860 |
| 3 | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs | -425 | -291,195 |
| 4 | Replacing incandescent light bulbs with compact fluorescent bulbs | -405 | -277,095 |
| 5 | Replacing incandescent light bulbs with light emitting diodes | -346 | -236,931 |
| 6 | 200L solar water heaters – with subsidy | -273 | -187,248 |
| 7 | 200L solar water heaters | -255 | -174,382 |
| 8 | 300L solar water heaters – with subsidy | -180 | -123,406 |
| 9 | 300L solar water heaters | -160 | -109,716 |
| 10 | Improved cookstoves (JICO model) | -113 | -77,128 |
| 11 | Improved cookstoves (SAVE80 model) | -89 | -60,830 |
| 12 | Replacing compact fluorescent bulbs with light emitting diodes | 19 | 13,166 |
| 13 | 200W solar home system | 224 | 153,524 |
| 14 | 80W solar home system | 336 | 229,965 |
| 15 | 120W solar home system | 350 | 239,779 |
| 16 | Replacing charcoal stoves with LPG stoves | 367 | 251,193 |
| 17 | 30W solar home system | 510 | 349,102 |

Table 6: League table of the carbon-effectiveness of low-carbon measures in the residential sector.

| Rank: | Measure: | ktCO2-e |
|---|---|---|
| 1 | 300L solar water heaters – 50,000 installed by 2032 | 481 |
| 2 | 200L solar water heaters – 50,000 installed by 2032 | 321 |
| 3 | Replacing incandescent light bulbs with light emitting diodes | 281 |
| 4 | 300L solar water heaters – 30,000 installed by 2032 | 289 |
| 5 | Replacing incandescent light bulbs with compact fluorescent bulbs | 258 |
| 6 | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs | 258 |
| 7 | Improved cookstoves (SAVE80 model) | 203 |
| 8 | 200L solar water heaters – 30,000 installed by 2032 | 192 |
| 9 | Replacing compact fluorescent bulbs with light emitting diodes | 148 |
| 10 | Improved cookstoves (JICO model) | 90 |
| 11 | 300L solar water heaters – 10,000 installed by 2032 | 96 |
| 12 | 200L solar water heaters – 10,000 installed by 2032 | 64 |
| 13 | 200W solar home system – 15,000 installed by 2032 | 18 |
| 14 | Replacing charcoal stoves with LPG stoves | 13 |
| 15 | 200W solar home system – 10,000 installed by 2032 | 12 |
| 16 | 120W solar home system – 15,000 installed by 2032 | 11 |
| 17 | Building energy efficiency – training workshops | 10 |
| 18 | 80W solar home system –15,000 installed by 2032 | 7 |
| 19 | 120W solar home system – 10,000 installed by 2032 | 7 |
| 20 | 200W solar home system – 5,000 installed by 2032 | 6 |
| 21 | 80W solar home system – 10,000 installed by 2032 | 5 |
| 22 | Replacing kerosene lamps with solar lamps | 4 |
| 23 | 120W solar home system – 5,000 installed by 2032 | 4 |
| 24 | 30W solar home system – 15,000 installed by 2032 | 3 |
| 25 | 80W solar home system – 5,000 installed by 2032 | 2 |
| 26 | 30W solar home system – 10,000 installed by 2032 | 2 |
| 27 | 30W solar home system – 5,000 installed by 2032 | 1 |

Cost effective

Cost neutral

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

## Options Appraisal – Commercial and Public Sector

**Table 7: League table of the cost-effectiveness of low-carbon measures in the commercial and public sector.**

| Rank: | Measure: | USD/tCO2-e | RWF/tCO2-e |
|---|---|---|---|
| 1 | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs | -425 | -291,195 |
| 2 | Replacing incandescent light bulbs with compact fluorescent bulbs | -405 | -277,095 |
| 3 | Street lighting: replacing high pressure sodium bulbs with LED bulbs | -349 | -239,165 |
| 4 | Replacing incandescent light bulbs with light emitting diodes (LEDs) | -346 | -236,931 |
| 5 | 2.5kWp solar panel | -231 | -158,435 |
| 6 | 1.5kWp solar panel | -231 | -158,435 |
| 7 | Replacing compact fluorescent tubes with LED tubes | -192 | -131,834 |
| 8 | 300L solar water heater with subsidy | -180 | -123,406 |
| 9 | 300L solar water heater | -160 | -109,716 |
| 10 | Replacing compact fluorescent bulbs with light emitting diodes (LEDs) | 19 | 13,166 |
| 11 | Building energy efficiency standards | 704 | 481,996 |



**Table 8: League table of the carbon-effectiveness of low-carbon measures in the commercial and public sector.**

| Rank: | Measure: | ktCO2-e |
|---|---|---|
| 1 | Replacing compact fluorescent tubes with LED tubes – 100,000 tubes | 72 |
| 2 | Replacing incandescent light bulbs with light emitting diodes – 100,000 bulbs | 60 |
| 3 | Building energy efficiency standards | 48 |
| 4 | 2.5kWp solar panel – 3,000 installed by 2032 | 39 |
| 5 | Replacing compact fluorescent tubes with LED tubes – 50,000 tubes | 36 |
| 6 | Street lighting: replacing high pressure sodium bulbs with LED bulbs | 35 |
| 7 | Replacing incandescent light bulbs with light emitting diodes – 50,000 bulbs | 30 |
| 8 | 300L solar water heater with subsidy – 3,000 installed by 2032 | 29 |
| 9 | 300L solar water heater – 3,000 installed by 2032 | 29 |
| 10 | 2.5kWp solar panel – 2,000 installed by 2032 | 26 |
| 11 | 1.5kWp solar panel – 3,000 installed by 2032 | 24 |
| 12 | 300L solar water heater with subsidy – 2,000 installed by 2032 | 19 |
| 13 | 300L solar water heater – 2,000 installed by 2032 | 19 |
| 14 | 1.5kWp solar panel – 2,000 installed by 2032 | 16 |
| 15 | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs – 100,000 bulbs | 15 |
| 16 | Replacing incandescent light bulbs with compact fluorescent bulbs – 100,000 bulbs | 15 |
| 17 | 2.5kWp solar panel – 1,000 installed by 2032 | 13 |
| 18 | 300L solar water heater with subsidy – 1,000 installed by 2032 | 10 |
| 19 | 300L solar water heater – 1,000 installed by 2032 | 10 |
| 20 | 1.5kWp solar panel – 1,000 installed by 2032 | 8 |
| 21 | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs – 50,000 bulbs | 7.3 |
| 22 | Replacing incandescent light bulbs with compact fluorescent bulbs – 50,000 bulbs | 7.3 |
| 23 | Replacing compact fluorescent bulbs with light emitting diodes – 100,000 bulbs | 4.8 |
| 24 | Replacing compact fluorescent bulbs with light emitting diodes – 50,000 bulbs | 2.4 |

# Sector Focus
## The Industrial Sector



# Sector Focus – The Industrial Sector

### The Impacts of Business as Usual Trends

Thanks to a decade of sustained growth in Rwanda, the total value of manufacturing output in real terms is rapidly approaching the pre-genocide maximum. In per capita terms, however, output in 2011 was only half of what it had been in the late 1980s, suggesting that the 1994 crisis has had long-term impacts on the country's industrialisation process (Gathani and Stoelinga, 2013).

Data on energy use by industry is not available at the city scale, so we present historical and projected trends at the national scale in Figure 4. Under business as usual conditions, energy use by the industrial sector in Rwanda is projected to increase by 42.3% over the next fifteen years, from 516.6TJ in 2015 to 734.9 TJ in 2032. During this period, we anticipate some fuel switching to electricity as the reliability and capacity of the grid increase.

**Figure 14. Energy use by fuel type in the manufacturing, construction and non-fuel mining industries in Rwanda between 2000 and 2032. Energy use data is not available at the city-scale.**

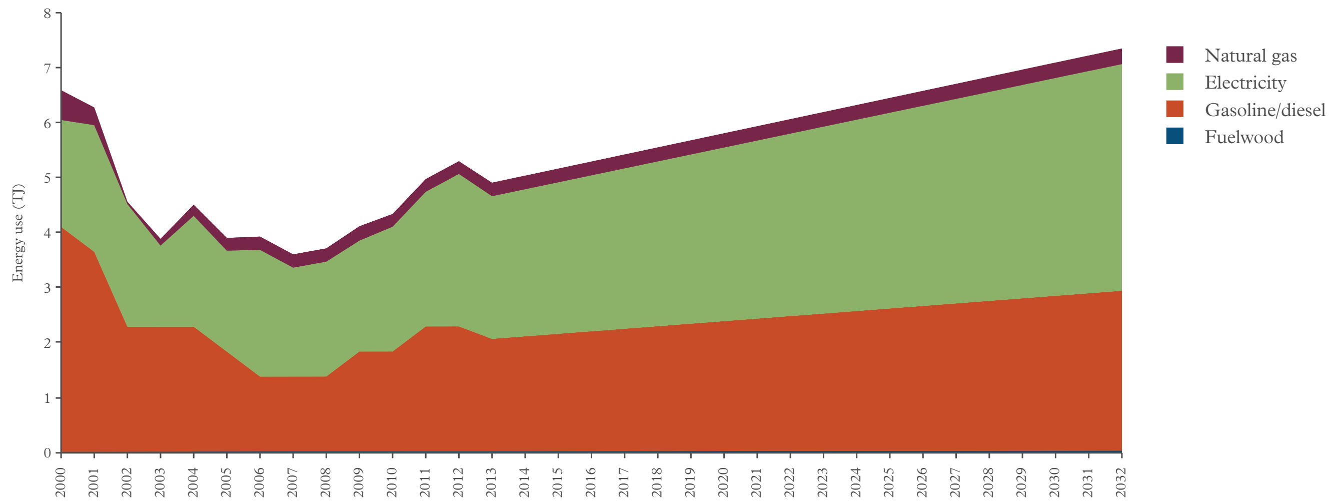
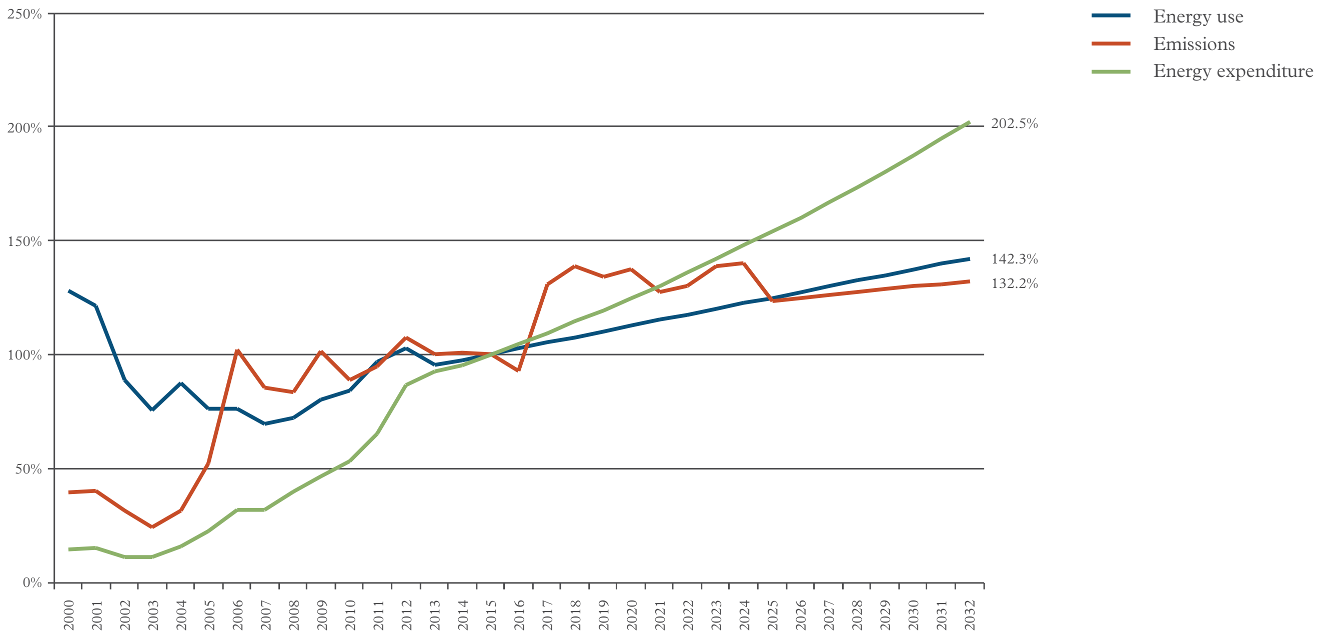


Figure 15: Indexed energy consumption, energy bills and emissions in the manufacturing, construction and non-fuel mining industries in Rwanda between 2000 and 2032. The bulge in emissions reflects the higher carbon intensity of electricity between 2017 and 2025.




Most industrial activity has historically been and is currently concentrated in Kigali. Large manufacturing firms with factories in the city include Ameki Color (paint products), Bakhresa Grain Milling, Bralirwa (brewing), Inyange (milk products), Premier Tobacco Company, Ruliba Clays (building materials), Sulfo Industries (cosmetics, soaps, plastics and mineral water), Tolirwa (roof sheeting) and Utexrwa (textiles). However, many firms remain in the start-up or growth phase, and most are operating well below optimal capacity due to difficulties importing raw materials or lack of demand (Gathani and Stoelinga, 2013).

We present below a new overview of employment and revenue by industrial sub-sector in Kigali. Manufacturing of construction materials is the largest employer, following by fast-moving consumer goods and agro-processing. However, the agro-processing industry generates the most annual revenue, followed by beverages and construction materials. This excludes jobs and revenue generated in the informal sector.

## The Potential for Carbon Reduction – Investments and Returns

No detailed information is available on energy use by or carbon emissions from industry in Rwanda. This limits the scope to reliably assess the economic or carbon savings of different low-carbon measures available to manufacturing firms within the city.

The IPCC estimates that "energy intensity of the industrial sector globally could be reduced by approximately up to 25% compared to current level through widescale upgrading, replacement and deployment of best available technologies, particularly in countries where these are not in practice and for non-energy intensive industries… Through innovation, additional reductions of approximately up to 20% in energy intensity may potentially be realized before approaching technological limits in some energy intensive industries." (Fischedick et al., 2014: pp 743). The IPCC further adds that several emission-reducing options in the industrial sector are cost-effective and profitable (Fischedick et al., 2014).

Figure 16. Full-time equivalent employment by industrial sub-sector in Kigali in 2012.

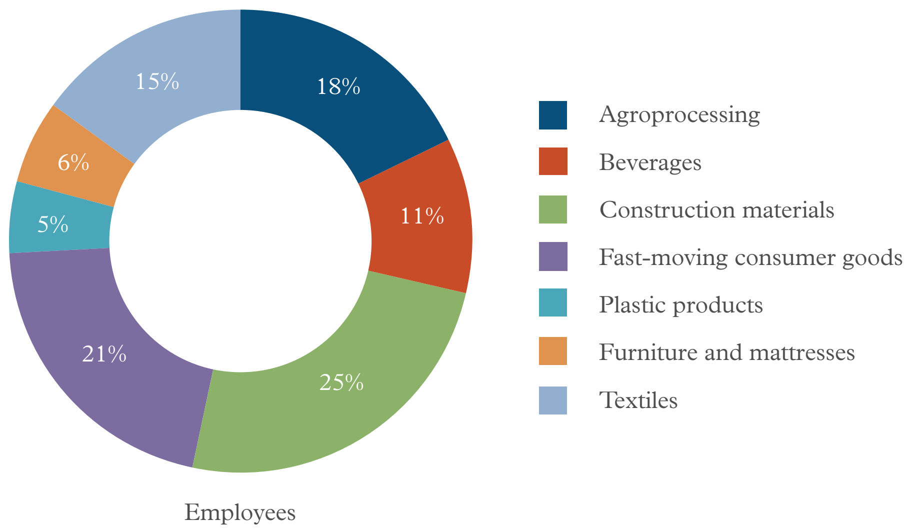
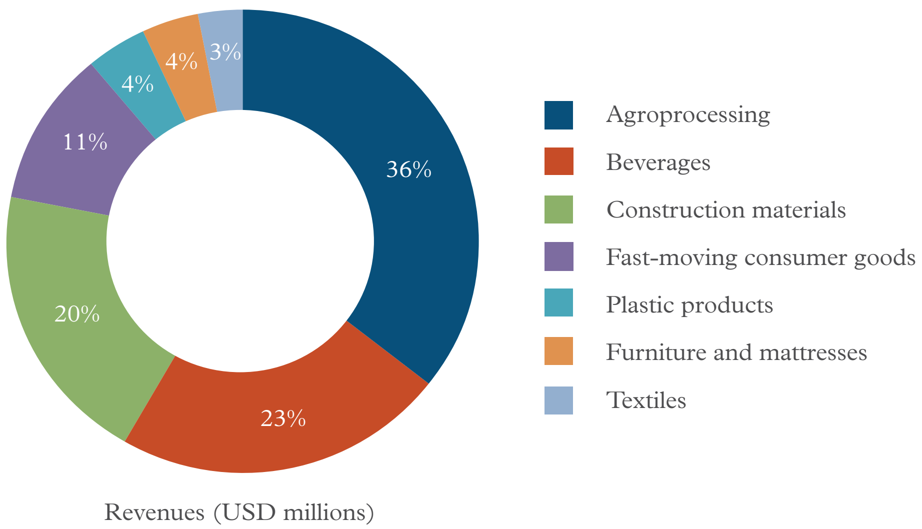



Figure 17. Annual revenue by industrial sub-sector in Kigali in 2012.



# Sector Focus

## The Transport Sector



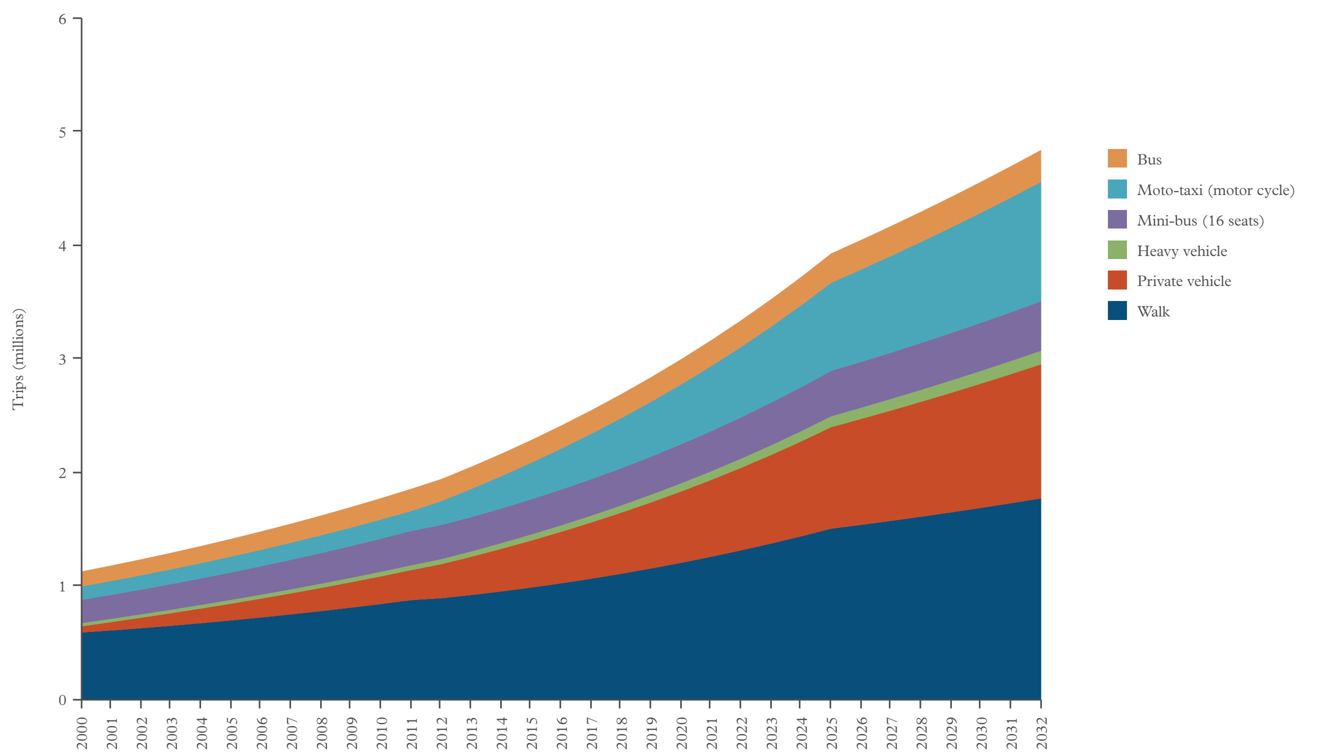
# Sector Focus – The Transport Sector

### The Impacts of Business as Usual Trends

A growing population and rising wealth have led to a dramatic increase in vehicle ownership in Kigali. Between 2005 and 2011, household car ownership rates rose on average at 5.8% per year, leading to higher congestion, energy use, emissions and expenditure on travel. If these trends continue through 2032, energy consumption will rise by 171.1%, from 1.5 TWh in 2015 to 4.0 TWh in 2032. With constant carbon intensity of energy, emissions will increase by 170.1% under business as usual conditions, from 378.9 kt$CO_2$e in 2015 to 1023.2 kt$CO_2$e in 2032.When combined with increasing real energy prices, energy expenditure in the transport sector is expected to rise 283.8%, from RWF 158.2 billion (USD 231.0 million) in 2015 to RWF 607.1 billion (USD 886.4 million) in 2032.

Transport policy in Rwanda (excluding aviation) is coordinated by the Ministry of Infrastructure (MINIFRA) and the Rwandan Transport Development Authority (RTDA), a semi-autonomous body under MINIFRA. Key policies of the transport sector are outlined in the National Transport Policy 2008, the National Transport Sector Investment Strategy 2002 and the Integrated National Transport Strategy 2011– 2015. These policies are developed to achieve Rwanda's Vision 2020 goals by "[reducing] constraints to transport in order to promote sustainable economic growth and contribute to poverty reduction" (MINIFRA 2008:8). Specific policies being implemented in Kigali include the rollout of a smart fare collection system and a detailed feasibility study for a BRT system.

**Figure 18. Trips by mode share in Kigali between 2000 and 2032.**

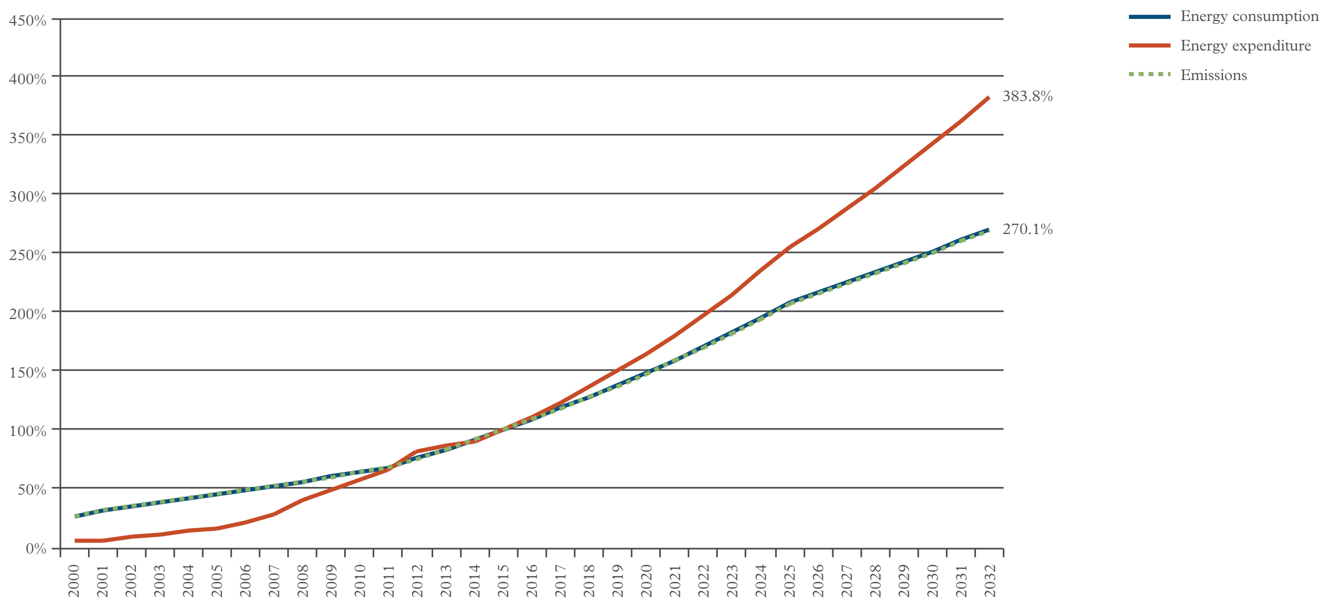


## The Potential for Carbon Reduction – Investments and Returns

We find that – compared to 2015 – these 'business as usual' trends in carbon emissions could be reduced by:

- 11.1% through cost-effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of RWF 332.0 billion (USD 477.8 million), generating annual savings of RWF 47.1 billion (USD 67.8 million), paying back the investment in 7.1 years and generating annual savings for the lifetime of the measures.
- 16.5% 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 RWF 533.5 billion (USD 767.8 million), generating annual savings of RWF 65.4 billion (USD 94.1 million), paying back the investment in 8.1 years and generating annual savings for the lifetime of the measures.

**Figure 19. Indexed energy consumption, energy bills and emissions in the transport sector in Kigali between 2000 and 2032.**

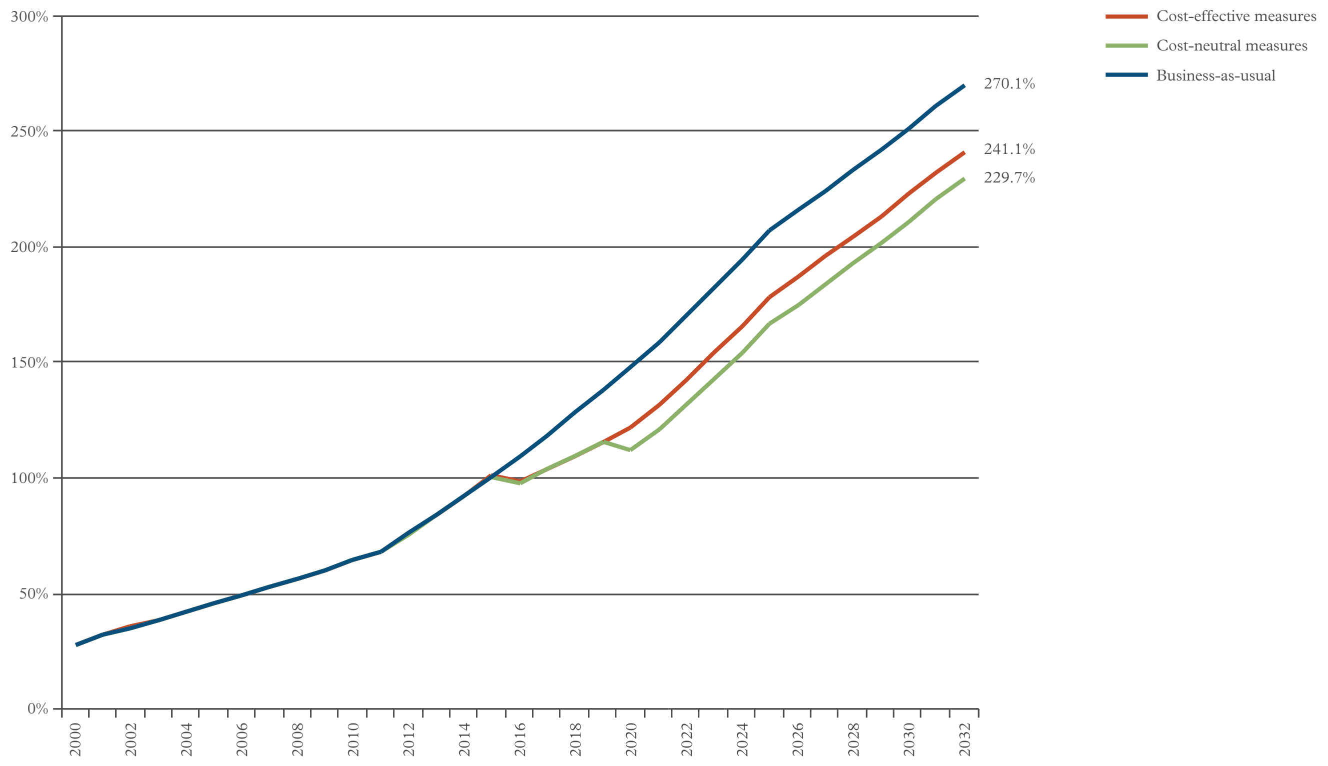





## Options Appraisal

In this options appraisal, we distinguish between a public and private case for investment. The private case is from the perspective of an investor seeking to recover their costs and generate a real return at or above 5% per annum through revenue generation. The public case is from the perspective of the city as a whole, and tests whether the city could recover the cost of the investment and generate a return at or above 5% per annum through wider benefits. For example, the private case for a Bus Rapid Transport (BRT) system compares the capital and operating costs against expected revenues from bus fares. The public case for a BRT system compares the capital and operating costs against city-wide fuel savings.

**Figure 20: Emissions from the transport sector under three different investment scenarios, indexed against 2015 emissions, between 2000 and 2032.**



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 transport sector.**

| Rank: | Measure: | USD/tCO2-e | RWF/tCO2-e |
|---|---|---|---|
| 1 | Parking meters in CBD (public case) | -691 | -480,189 |
| 2 | Bike lane investments (public case) | -676 | -469,565 |
| 3 | Electric bike - 5% of trips 2032 (public case) | -650 | -451,672 |
| 4 | Electric bike - 5% of trips 2032 (private case) | -647 | -449,582 |
| 5 | Import age restrictions <15 (public case) | -360 | -249,951 |
| 6 | Import age restrictions <10 (public case) | -234 | -162,478 |
| 7 | Euro IV standards (public case) | -180 | -125,401 |
| 8 | Bus network expansion - doubling of 2015 capacity by 2032 (public case) | -71 | -49,006 |
| 9 | Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (public case) | -70 | -48,563 |
| 10 | BRT Line 1 - CBD to Rususoro (public case) | -58 | -40,108 |
| 11 | Bus network expansion - doubling of 2015 capacity by 2032 (private case) | -12 | -8,573 |
| 12 | BRT Line 2 - CBD to Gahanga (public case) | -7 | -4,538 |
| 13 | Parking meters in CBD (private case) | -4 | -2,872 |
| 14 | Import age restrictions <10 (government case) | 0.0 | 0.0 |
| 15 | Euro IV standards (government case) | 0.4 | 0.0 |
| 16 | Import age restrictions <15 (government case) | 3 | 1,847 |
| 17 | Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (private case) | 37 | 25,752 |
| 18 | Bike lane investments (private case) | 56 | 39,158 |
| 19 | BRT Line 1 - CBD to Rususoro (private case) | 547 | 379,854 |
| 20 | BRT Line 2 - CBD to Gahanga (private case) | 598 | 415,423 |



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

**Table 10: League table of the carbon-effectiveness of low-carbon measures in the transport sector.**

| Rank: | Measure: | ktCO2-e |
|---|---|---|
| 1 | Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (public case) | 1,340 |
| 2 | Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (private case) | 1,340 |
| 3 | Bus network expansion - doubling of 2015 capacity by 2032 (public case) | 1,300 |
| 4 | Bus network expansion - doubling of 2015 capacity by 2032 (private case) | 1,300 |
| 5 | Euro IV standards (public case) | 865 |
| 6 | Euro IV standards (government case) | 865 |
| 7 | Import age restrictions <10 (public) | 597 |
| 8 | Import age restrictions <10 (government case) | 597 |
| 9 | BRT Line 1 - CBD to Rususoro (public case) | 233 |
| 10 | BRT Line 1 - CBD to Rususoro (private case) | 233 |
| 11 | Electric bike - 5% of trips 2032 (public case) | 355 |
| 12 | Electric bike - 5% of trips 2032 (private case) | 355 |
| 13 | BRT Line 2 - CBD to Gahanga (public case) | 256 |
| 14 | BRT Line 2 - CBD to Gahanga (private case) | 256 |
| 15 | Import age restrictions <15 (public case) | 201 |
| 16 | Import age restrictions <15 (government case) | 201 |
| 17 | Parking meters in CBD (public case) | 155 |
| 18 | Parking meters in CBD (private case) | 155 |
| 19 | Bike lane investments (public case) | 149 |
| 20 | Bike lane investments (private case) | 149 |

# Sector Focus

## The Waste Sector



# Sector Focus – The Waste Sector

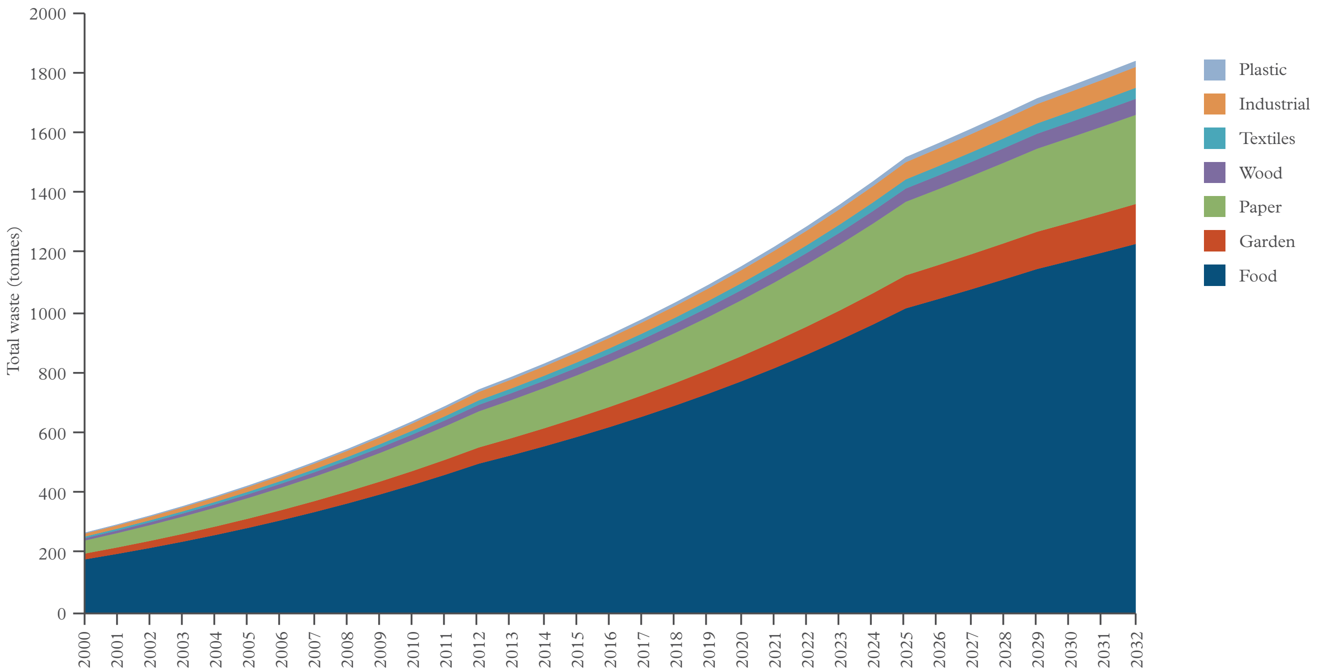
### The Impacts of Business as Usual Trends

Population and economic growth are leading to a significant increase in waste generation in Kigali. Waste generation today is approximately 1.8kg/per capita/day, but it is projected to rise to 2.0kg/per capita/day by 2030 (REMA, 2013) and will exceed a million tonnes per year by 2020. Food waste currently accounts for two thirds of all waste production. The composition of waste in the city is likely remain broadly constant to 2032, as this variable typically does not change much as a country moves from low- to middle-income status (World Bank, 2012). Currently, two thirds of all waste is disposed in landfills. The remainder is either burned or informally disposed.

The Rwandan government is aware of the challenges that urbanisation and high population growth are creating for waste management and sanitation. This has led to the development of a clear national policy aimed at minimising waste production, increasing access to adequate sanitation services, promoting recycling and encouraging private sector participation in waste management. Indeed, the Kigali Master Plan (Surbana International Consultants, 2013) and Vision 2020 (MINECOFIN, 2012) both prioritise the development of an integrated waste management system.

Waste management is the responsibility of several government ministries, authorities and agencies in the country. The sector is regulated by the Rwanda Utilities Regulatory Authority (RURA) and Rwanda Environment Management Authority (REMA). These bodies develop sector wide policies, regulations and guidelines, and regulate and issue permits to private companies, cooperatives and individuals involved in waste collection and transportation. There are currently twelve waste collection companies servicing Kigali. The City of Kigali and the Energy, Water and Sanitation Agency (EWSA) are responsible for planning and implementing waste management and sanitation projects in the city.

**Figure 21: Waste production by type in Kigali, 2000 to 2032.**




2 The solid waste management strategic plan has lower estimates of per capita waste production (City of Kigali and BTC Rwanda, 2012).

## The Potential for Carbon Reduction – Investments and Returns

We find that – compared to 2015 – these 'business as usual' trends in carbon emissions could be reduced by:

- 78.7% through cost-effective investments that would more than pay for themselves on commercial terms over their lifetime. This would require investment of RWF 11.7 billion (USD 17.1 million), generating annual savings of RWF 5.6 billion (USD 8.1 million), paying back the investment in 2.1 years and generating annual savings for the lifetime of the measures.
- 84.1% 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 RWF 23.2 billion (USD 33.9 million), generating annual savings of RWF 3.0 billion (USD 4.3 million), paying back the investment in 7.9 years and generating annual savings for the lifetime of the measures.

Emissions from the waste sector are expected to rise dramatically, from 384.7 kt$CO_2$e in 2015 to 1.0 Mt$CO_2$e in 2032, an increase of 167.5%.

**Figure 22: Carbon emissions (ktCO2e) from the waste sector in Kigali between 2000 and 2032.**

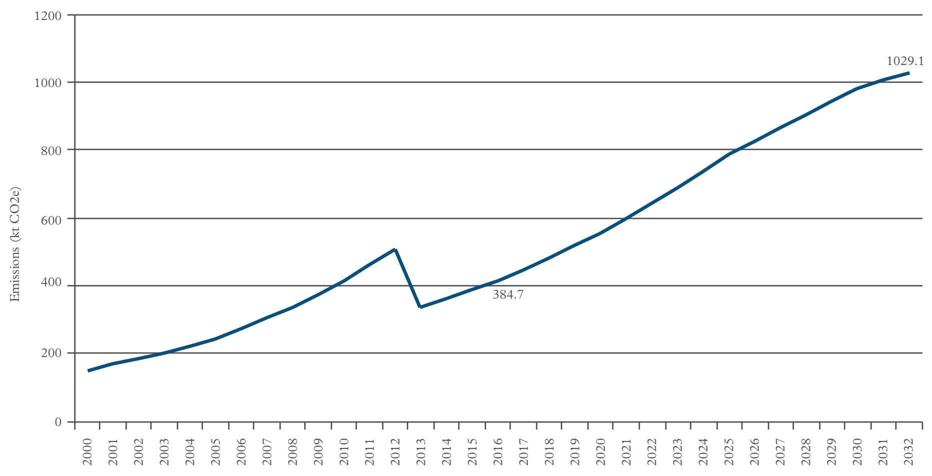
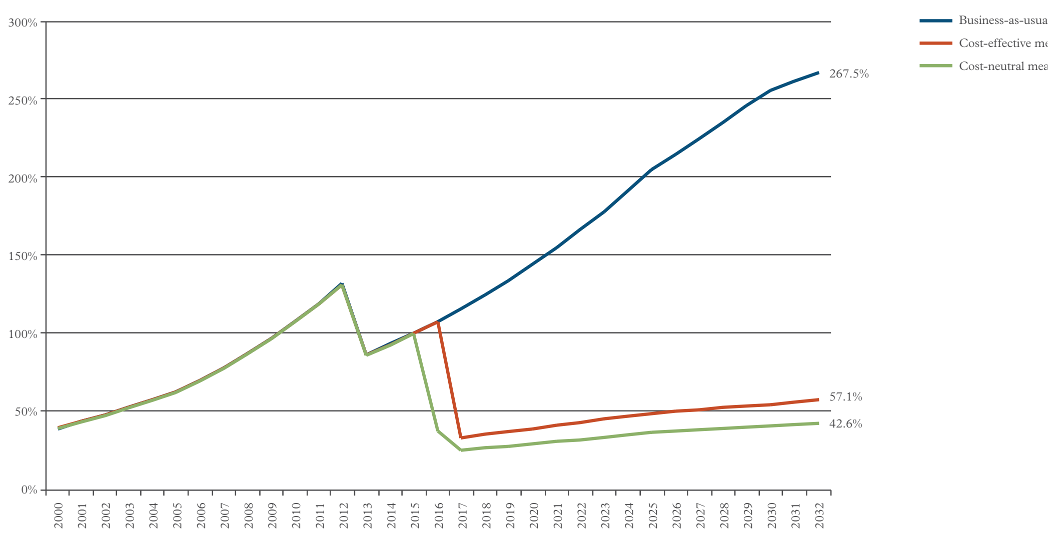



**Figure 23: Emissions from the waste sector under three different investment scenarios, indexed against 2015 emissions, between 2000 and 2032.**






Cost effective

Cost neutral

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

## Options Appraisal

**Table 11: League table of the cost-effectiveness of low-carbon measures in the waste sector.**

| Rank: | Measure: | USD/tCO2-e | RWF/tCO2-e |
|---|---|---|---|
| 1 | LFG utilisation | -5 | - 3,440 |
| 2 | Centralised anaerobic digestion to electricity | -0 | - 284 |
| 3 | Home composting (30%) | 1 | 737 |
| 4 | Home composting (15%) | 1 | 773 |
| 5 | Landfill gas flaring (65%) | 3 | 1,850 |
| 6 | Landfill gas flaring (25%) | 6 | 4,057 |
| 7 | Recycling (20%) | 7 | 4,927 |
| 8 | Recycling (40%) | 8 | 5,707 |
| 9 | Home biogas production | 9 | 6,211 |
| 10 | Central composting (19%) | 28 | 18,835 |
| 11 | Central composting (30%) | 31 | 21,365 |

**Table 12: League table of the carbon-effectiveness of low-carbon measures in the waste sector.**

| Rank: | Measure: | ktCO2-e |
|---|---|---|
| 1 | Centralised anaerobic digestion to electricity | 12,736 |
| 2 | Landfill gas utilisation | 9,133 |
| 3 | Landfill gas flaring (65%) | 5,512 |
| 4 | Landfill gas flaring (20%) | 2,513 |
| 5 | Recycling (40%) | 1,918 |
| 6 | Home Biogas production | 1,658 |
| 7 | Central composting (30%) | 1,024 |
| 8 | Home composting (30%) | 1,024 |
| 9 | Recycling (20%) | 1,056 |
| 10 | Home composting (15%) | 863 |
| 11 | Central composting (19%) | 657 |

# Chapter 5. Discussion

Between 2000 and 2015, rapid economic and population growth fuelled massive increases in energy use, emissions and energy bills in Kigali. During this period, even as Kigali's economy grew at nearly 10% per year, emissions and energy use per unit of GDP remained relatively constant. This illustrates the critical importance of improving access to modern energy during the early stages of development.

Looking forward to 2032, the consumption of energy per unit of GDP is expected to fall quite significantly. However, total energy consumption will increase due to rising demand for electricity from households and for transport fuel from vehicles. Since the carbon intensity of energy remains largely constant, per capita emissions will increase roughly in proportion to per capita energy use. Total emissions are expected to rise 184.9% by 2032 over 2015 levels.

The most significant source of new emissions comes from the transport sector, where emissions are projected to increase by 0.6Mt$CO_2$ annually by 2032. However, the fastest emissions growth is found in the commercial and residential sector, where emissions will grow 7.4% per annum. The accompanying increase in demand for energy, combined with population growth, will lead to expenditure on energy rising 249.7%, or more than threefold, by 2032. While domestic energy sources, including natural gas from Lake Kivu, are under development, these figures suggest that Rwanda is on a path to increased expenditure, and reliance, on foreign sources of energy.

This study reveals that a compelling case exists for broad-based investment in low-carbon development in Kigali. By 2032, the city can reduce emissions by against 39.0% the business-as-usual scenario, through cost-effective investments that would pay for themselves in 5.3 years on commercial terms. If the profits from those investments were then re-invested in low-carbon measures, Kigali could reduce its emissions 42.6% relative to the business-as-usual trends and recover the investment in 7.5 years. These measures would continue to generate annual savings over their lifetimes.

For reference, the opportunities for carbon savings are much higher in Kigali than in middle-income cities evaluated using a similar methodology. Comparable studies of Kolkata (India) and Palembang (Indonesia) suggested that these cities could reduce city-scale emissions by 20.7% and 24.1% respectively (Gouldson et al., 2015). While Kigali could save 1.5% of city-scale GDP per annum through these investments, the opportunities are slightly larger in Kolkata at 1.7% of GDP and substantially larger in Palembang at 9.5% of GDP (Gouldson et al., 2015).

The Economics of Low Carbon Cities: Kigali, Rwanda reveals that policymakers need to take a strategic approach to low-carbon development Kigali. Investments in the waste sector account for 74.1% of potential cost-effective emissions savings over the period to 2032. The waste sector therefore presents an opportunity that can deliver near-term emission reductions in Kigali while generating economic returns for investors.

Future emissions growth, however, will increasingly come from the transport, residential, commercial and industrial sectors. Over the period 2000-2015 emissions from the transport sector grew 8.9% per year and emissions from the commercial and public buildings sector grew 8.1% while in the waste sector emissions grew only 6.4% annually. Looking forward to 2032, diminishing per capita increases in emissions from waste is expected to continue while emissions from other sectors of the economy will grow steadily.

This finding has two important implications. Firstly, as development continues in Kigali, the major sources of emissions will look increasingly similar to those of middle-income economies. Consequently, while investments in waste produce the largest impacts today, investments in buildings and transport will have the largest impact in the near future. Secondly, Kigali has a tremendous opportunity to avoid 'lock in' to high energy use and emissions from these sectors if actions are taken today before large investments supporting the business-as-usual pathway are made.

The buildings and vehicle stock that exist in 2015 will be little more than one-quarter of the building and vehicle stock that will exist in 2032 at current rates of growth. Actions to set Kigali on a more sustainable path include investments in public transport, supporting truly low-carbon technologies (such as electric bikes), investments in geothermal electricity generation and spatial planning. Efforts such as emission standards for vehicles, small-scale solar in buildings and solar hot water heaters are not insignificant, but ultimately offer only a partially decarbonised development path.

While this research focuses on the economic case for low-carbon investments, it is imperative that policymakers identify and implement those measures that support broader economic and human development goals. Economically attractive measures in the transport sector, including an expansion of bus networks and investment in bike lanes, would enhance urban mobility (particularly for the poor), reduce exposure to volatile energy prices and reduce congestion as the city grows. Investments in solar lamps and improved charcoal cook stoves would substantially reduce the risk of burns while improving indoor air quality. Investments in solar PV and solar water heating enhance energy security and ensure that households capture economics benefits from low-carbon development. 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 Kigali. The compelling economic case for low-carbon investment, coupled with social co-benefits and growing public engagement with environmental issues, provide a strategic opportunity to integrate climate considerations into urban planning.

# Chapter 6. Conclusion and Recommendations

Rapid development in Kigali is leading to substantial increases in per capita energy use and emissions. Growth is even faster at the city-scale, as the population of Kigali is increasing quickly. Although economic growth is anticipated to decouple from emissions in relative terms, a continuation of business as usual trends will lead to very significant increases in energy use, energy bills and emissions. While an increase in energy consumption is to be welcomed for development reasons, Kigali's current trajectory will leave it highly dependent on imported fossil fuels. Quite apart from the implications for climate change, this will have negative consequences for social equity and liveability in Kigali as energy costs, congestion and pollution levels rise.

This research reveals that there are many economically attractive opportunities to invest in low-carbon options in Kigali. These measures not only offer a compelling investment opportunity at a range of scales, but could generate a wide array of co-benefits such as improved energy access, enhanced mobility and better air quality. The scale and diversity 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 Kigali to secure the investments and develop the delivery models needed to pursue climate action. Some of the low-carbon measures could be commercially attractive, while others may only be viable with international climate finance or development assistance. Many of the opportunities would benefit from the support of enabling policies from government, where Rwanda has shown impressive leadership to date.

We stress that economic considerations should not be the only consideration for a low-carbon development model in urban Rwanda. Decision-makers should also consider issues relating to the equity, inclusivity and broader sustainability of the different options. 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 helps to build public interest in, and unlock new finance streams for, ambitious climate action in Kigali.



# References


AfDB. 2013. Rwanda Energy Sector Review and Action Plan. African Development Bank. Available from: http://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Rwanda_-_Energy_Sector_Review_and_Action_Plan.pdf [retrieved 06/09/2015]

Byamukama B, Carey C, Cole M, Dyszynski J, Warnest M. 2011. Baseline Report: National Strategy on Climate Change and Low Carbon Development for Rwanda. Smith School of Enterprise and the Environment, University of Oxford. Available from: http://www.smithschool.ox.ac.uk/library/reports/Rwanda-Baseline-Final.pdf [retrieved 14/11/2015]

City of Kigali and BTC Rwanda. 2012. Data Collection and Analysis of Solid Waste Management in the City of Kigali. City of Kigali.

City of Kigali. 2013a. Kigali Transportation Master Plan. Available from: http://www.masterplan2013.kigalicity.gov.rw/downloads/Docs/RWF1101_04_Kigali%20Transportation%20Master%20Plan_04062013-s.pdf [retrieved 30/10/2015]

City of Kigali. 2013b. Kigali City Analysis Benchmarking and Vision Report. Available from: http://www.masterplan2013.kigalicity.gov.rw/downloads/Docs/RWF1101_02_Kigali%20City_Analysis%20Benchmarking%20and%20Vision%20Report_03062013-s.pdf [retrieved 28/05/2015]

Downing T, Watkiss P, Dyszynski J, Butterfield R, Devisscher T, Pye S, et al... 2009. Economics of Climate Change in Rwanda. Stockholm Environment Institute. Available from: http://www.sei-international.org/publications?pid=1579 [retrieved 05/06/2015]

EIA. 2012. International Energy Statistics. U.S. Energy Information Administration. Available from: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=90&pid=45&aid=8&cid=regions&syid=1980&eyid=2010&unit=MMTCD [retrieved 06/09/2015]

Ermert V, Fink AH, Paeth H. 2013. The potential effects of climate change on malaria transmission in Africa using bias-corrected regionalised climate projections and a simple malaria seasonality model. Climatic Change. 120(4) 741-754 doi:10.1007/s10584-013-0851-z

Fischedick M, Roy J, Abdel-Aziz A, Acquaye A, Allwood JM, Ceron J-P, Geng Y, Kheshgi H, Lanza A, Perczyk D, Price L, Santalla E, Sheinbaum C, Tanaka K. "2014: Industry". In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Fisher S, Fikreyesus D, Islam N, Kallore M, Kaur N, Shamsuddoha Md, Nash E, Rai N, Tesfaye L, Rwirahira J. 2014. Bringing together the low-carbon and resilience agendas: Bangladesh, Ethiopia, Rwanda. International Institute for Environment and Development. Available from: http://pubs.iied.org/pdfs/10099IIED.pdf? [retrieved 06/09/2015]

Gathani S, Stoelinga D. 2013. Understanding Rwanda's Agribusiness and Manufacturing Sectors. International Growth Centre and Laterite. Available from: http://www.value-chains.org/dyn/bds/docs/862/UnderstandingRwandaAgribusinessandManufacturingSe.pdf [retrieved 14/10/2015]

Gouldson A, Colenbrander S, Sudmant AH, McAnulla F, Kerr N, Sakai P, Hall S, Papargyropoulou E, Kuylenstierna J. 2015. Exploring the economic case for climate action in cities. Global Environmental Change. 35 93-105 doi:10.1016/j.gloenvcha.2015.07.009

Henninger SM. 2013. When Air Quality Becomes Deleterious—A Case Study for Kigali, Rwanda. Journal of Environmental Protection. 4, 1-7.

JICA. 2015. The Project for Preparation of Electricity Development Plan for Sustainable Geothermal Energy Development in Rwanda. Japanese International Cooperation Agency. Prepared for the Ministry for Infrastructure. [retrieved 30/03/2015]

KCC. 2011. About Kigali: City of Kigali a gateway to Rwanda. Kigali City Council. Available from: http://www. kigalicity.gov.rw/spip.php?article109 [retrieved on 2/10/2015].

MINECOFIN. 2012. Rwanda Vision 2020: Revised 2012. Ministry of Finance and Economic Planning, Rwanda. Available from: http://www.minecofin.gov.rw/fileadmin/templates/documents/NDPR/Vision_2020_.pdf [retrieved 06/09/2015]

MININFRA. 2008. National Urban Housing Policy for Rwanda. Ministry of Infrastructure, Rwanda. Available at: http://www.rha.gov.rw/fileadmin/user_upload/Documents/Laws_and_Regulation/National_Urban_housing_Policy_Dec_23.pdf [retrieved 10/06/2015]

MININFRA, GGGI. 2015. National Roadmap for Green Secondary City Development. Ministry of Infrastructure, Rwanda, and Global Green Growth Institute. Forthcoming.

Nash E, Ngabitsinze JC. 2014. Low-carbon resilient development in Rwanda. International Institute for Environment and Development. Available from: http://pubs.iied.org/pdfs/10065IIED.pdf? [retrieved 06/09/2015]

NISR. 2013. Statistical Yearbook 2012. National Institute of Statistics of Rwanda. Kigali. Available from: http://statistics.gov.rw/publications/statistical-yearbook-2012 [retrieved 28/05/2015]

NISR. 2014. Statistical Yearbook 2014. National Institute of Statistics of Rwanda. Available from: http://statistics.gov.rw/publications/statistical-yearbook-2014 [retrieved 06/09/2015]

OECD. 2015. OECD.Stat: Greenhouse gas emissions. DOI: 10.1787/data-00285-en

Oz Architecture, Kigali Conceptual Master Plan, Bolder Colorado, United States, 2007. Available from: http://ozarch.com/portfolio/kigali-master-plan/ [retrieved 05/06/2015]

REMA. 2013. Kigali State of Enviroment and Outlook Report. Rwandan Environment Management Authority. Kigali.

Republic of Rwanda. 2011. Green Growth and Climate Resilience: National Strategy for Climate Change and Low Carbon Development. Government of Rwanda and the Smith School of Enterprise and Environment (SSEE), University of Oxford. Available from: http://www.uncsd2012.org/content/documents/364Rwanda-Green-Growth-Strategy-FINAL.pdf [retrieved 06/09/2015]

Surbana International Consultants. 2013. Kigali Master Plan 2013. Available from: http://www.kcps.gov.rw/index.php?id=21#Master plan [retrieved 14/10/2015]

UN-Habitat 2008. "UN-Habitat Scroll of Honour Award". Available from: http://mirror.unhabitat.org/content.asp?typeid=19&catid=827&cid=6586 [retrieved 12/10/2015]

World Bank. 2012. What a Waste, A Global Review of Solid Waste Management. The World Bank

World Bank. 2014. Country Partnership Strategy for Rwanda FY2014-2018: Accelerating Economic Growth. Available from: http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/06/25/000333037_20140625113757/Rendered/PDF/889410CAS0P1300wanda0CPS000Volume02.pdf [retrieved 06/09/2015]

# Appendix A. Workshop Participants

| Name | Position | Institution |
|---|---|---|
| **Josh Whale** | CEO | Ampersand |
| **Emmanuel Hakizimana** | Managing Director | BESS Ltd |
| **Fatou Dieye** | Coordinator | City of Kigali |
| **Allaire Julilen** | Executive Manager | Cooperation for Urban Mobility in the Developing World (CODATU) |
| **Eric Murera** | Special Waste Officer | COPED Ltd |
| **Alex Mulisa** | Coordinator | Environmenta and Climate Change Fund (FONERWA) |
| **Mathieu Belanger** | Urban Planner | Global Green Growth Institute (GGGI) |
| **Leobard Banamwana** | Urban Planner | Global Green Growth Institute (GGGI) |
| **Brendan Maguire** | MD | Kigali Bus Services (KBS Ltd) |
| **Musoni Damas** | IDP Specialist | Ministry of Local Goernment (MINALOC) |
| **Janvier Iradukuunda** | Environmental Facilitator | Ministry of Local Goernment (MINALOC) |
| **Timothy Kayumba** | Green Economy Specialist | Ministry of Natural Resources (MINIRENA) |
| **Innocent Habimana** | Inland water transport Senior Engineer | Minstry of Infrastructure (MININFRA) |
| **Samuel Fell** | Economist | Minstry of Infrastructure (MININFRA) |
| **Theoneste Higaniro** | Renewable Energy Senior Engineer | Minstry of Infrastructure (MININFRA) |
| **Immaculate Mbabazi Rugema** | SE Social Development Planne | Minstry of Infrastructure (MININFRA) |
| **Malin Anderberg** | Project Coordinator | Mobisol |
| **Ernest Nkuba** | Hydropower Development Specialist | Rwanda Energy Group (REG Ltd) |
| **Turambe Twizere** | Hydropower Development Specialist | Rwanda Energy Group (REG Ltd) |
| **Denis Rugege** | Green Economy Advisor | Rwanda Environment Management Authority (REMA) |
| **Didas Bazirasa** | I/C Transport | Rwanda Federation of Transport Cooperatives |
| **Claude Butera** | Senior Architect | Rwanda Housing Authority (RHA) |
| **Edward Kyazze** | Urban Settlements Division Manager | Rwanda Housing Authority (RHA) |



# Appendix B. Data Sources, Methods and Assumptions for the Baseline

| Activity | Projection method | Key data in 2014 |
|---|---|---|
| **Energy Prices** | Data on electricity prices were obtained from the Statistical Yearbooks published annually by the National Institute of Statistics Rwanda (NISR, 2013, 2014, 2015a). Data on the price of charcoal in 2000 and 2005 were obtained from GEF (2005). Data on the price of fuelwood in 1995 and 2004 were obtained from Safari (2010). Data on the price of biomass energy, LPG and kerosene in 2008 were obtained from the Biomass Energy Strategy (MARGE, 2009a). Data on the price of LPG in 2010 was obtained from Kazoora (2010). Data on the price of kerosene were obtained from Mukaaya (2008), Businge (2015) and – assuming that pump prices for gasoline were equal to those for kerosene between 2000 and 2004 – the World Bank (2015a) Data on the price of charcoal and fuelwood in 2013 were obtained from Drigo et al. (2013).<br><br>Nominal energy prices were converted into real energy prices at 2014 levels using a consumer price index from the World Bank (2015b). An annual increase of 2% in real terms was assumed for all energy prices from 2015 to 2032. | Grid electricity:<br>RWF 158.0/kWh (residential)<br>RWF 149.0/kWh (industrial)<br><br>Diesel:<br>RWF 919/L<br><br>Gasoline:<br>RWF 989/L<br><br>Charcoal:<br>RWF 166.9/kg<br><br>Fuelwood:<br>RWF 81.3/kg (residential)<br><br>Kerosene:<br>RWF 1,010/L |
| **Exchange rates** | The annual exchange rates between Rwandan francs and US dollars between 2000 and 2005 were obtained from the CIA World Factbook (CIA, 2005). The annual midpoint exchange rates between 2006 and 2015 were obtained from OANDA (2015). | USD 1.00 = RWF 684.945 |
| **Electricity generation and emissions factor estimates** | Data on existing and historical electricity generation is drawn from BNEF (2015) and REMA (2014). Plans for new generation and investment costs though 2017/18 are drawn from MINIFRA (2011), JICA (2015) and updated through consultation with members of the ministry. Technical and non-technical losses are assumed to fall from 23% in 2014 to 15% by 2017 following MINIFRA (2011). Capacity factors and the efficiency of generation are calculated based on data from REMA (2014) and BNEF (2015). Electricity demand through 2032 is drawn from JICA (2015). | Rwandan electricity grid emissions factor 2015: 0.46 $tCO_2e/MWh$<br><br>Rwandan electricity grid estimate factor 2032 estimate (excluding losses): 0.41 $tCO_2e/MWh$ |

Continued

| Activity | Projection method | Key data in 2014 |
|---|---|---|
| **Buildings sector** | Data on electricity consumption in Kigali by private customers (excluding industry) and public sector customers were obtained from REG. Electricity consumption was projected to continue increasing at the same rate through to 2032, i.e. 11.2% and 16.1% per annum for private and public sector customers respectively.<br><br>Per capita consumption of fuelwood and charcoal was obtained from Drigo et al. (2013). Households depending primarily on charcoal for cooking consumed 194kg/pp/pa, while households depending primarily on fuelwood consumed 366kg/pp/pa. The average numbers of households using charcoal and fuelwood respectively as their preferred cooking fuels were obtained from the Integrated Households Living Conditions Survey (NISR, 2006, 2011, 2015b). Data on national demand for LPG between 2003 and 2007 was obtained from MARGE (2009), and we assumed that all LPG would be consumed in Kigali at this time. Data on consumption of LPG in Kigali in 2009 and 2020 under BAU conditions were obtained from Drigo et al. (2013).<br><br>Data on kerosene consumption per household was drawn from Lights for Life (2015), which estimated that a household depending on kerosene lamps would use around 1L per week. Data on the number of households using kerosene as the primary lighting source was drawn from the Integrated Household Living Conditions Surveys (NISR, 2006, 2011, 2015b).<br><br>Commercial and public consumption of fuelwood and charcoal in Kigali in 2009 and 2020 was obtained from Drigo et al. (2013). Based on historical trends, we prepared a baseline where consumption of charcoal was expected to increase at 6.9% per year and consumption of fuelwood expected to decrease at 1.7% per year. | Residential and commercial electricity use:<br>142.0 GWh<br><br>Public electricity use:<br>24.6 GWh<br><br>Residential charcoal consumption:<br>173.3 kilotonnes<br><br>Commercial and public charcoal consumption:<br>16.8 kilotonnes<br><br>Residential wood consumption:<br>126.5 kilotonnes<br><br>Commercial and public wood consumption:<br>21.1 kilotonnes<br><br>LPG consumption:<br>554 tonnes<br><br>Kerosene consumption:<br>550 kilolitres |
| **Industrial sector** | Data on employment numbers and annual revenue of individual firms were drawn from Gathani and Stoelinga (2013). This report provides an overview of manufacturing at a national level; firms manufacturing within Kigali were identified through online research. The following firms were included in Figures 4 and 5: Coffee Business Centre, Rwacof, Rwanda Trading Company, Rwashoscco, Minimex, Sosoma, Bakhresa Grain Milling, ICM (one third of operations), Sorwatom, Premier Tobacco Company, Bralirwa (soft drink processing); Inyange, Skol Brewery, Kigali Cement Company, Ameki Color, Ruliba Clays, Safintra, Simaco/Afrifoam, Tolirwa, Uframetal, Uprotur, Anik Industries, Kigali Steel and Aluminium Works, Suku Paper Works, Sulfo Industries, Aqua-San Rwanda, Roto Ltd, Société de Rwandaise de Chaussure, Manumental, Mutara Enterprises, Rwanda Foam and Utexrwa. Where a range was provided for number of employees or annual revenue, the midpoint was used. | |



Continued

| Activity | Projection method | Key data in 2014 |
|---|---|---|
| **Transport sector** | Mode share in Kigali in 2011 is drawn from SSI (2011a) revealed preference dataset. The number of trips per day, average vehicle speed, occupancy rates, travel time and walking distances by travel mode are drawn from SSI (2011b), hierarchical multimodal transport model. Planned infrastructure investments in Kigali are drawn from the Kigali City Master Plan, City of Kigali (2013), RTDA (2012) and through consolation city and national government officials. To forecast travel demand in 2032 as estimate of total trip demand is drawn from SSI (2011b). The number of trips by private transport is assumed to growth proportionately to the rate of growth of vehicle ownership (5.8%) and the proportion of trips made on foot and by heavy transport is held constant. The number of trips by bus is assumed to increase with the expected number of buses (holding occupancy constant) and trips by motos is estimated as the residual. | Mode share 2011:<br><br>Walking: 9%<br>Private vehicles: 24%<br>Heavy vehicles: 4%<br>Mini-bus: 28%<br>Moto-taxi: 16%<br>Bus: 18%<br><br>Business-as-usual mode share (2032):<br><br>Walking: 9%<br>Private Vehicles: 36%<br>Heavy Vehicles: 4%<br>Mini-bus: 16%<br>Moto-taxi: 25%<br>Bus: 10% |
| **Waste sector** | Information on the characteristics of the landfills serving Kigali was drawn from Bazimenyera (2012a). Waste composition, production per capita and disposal methods were drawn from Bazimenyera (2012b), UNEP (2013), and the Rwandan population and housing census' of 2006 and 2011 (NISR 2006, 2012). Cost of waste disposal was drawn from the Kigali City Master Plan, City of Kigali (2013). Waste composition is assumed to remain constant through 2032 and to rise from 1.8 kg per capita per day in 2011 to 2.0 kg per capita per day in 2030. | In 2014, Kigali generated 880,155 tonnes of waste.<br><br>Waste composition:<br><br>Food: 67%<br>Garden: 7%<br>Paper: 16%<br>Wood: 3%<br>Textiles: 2%<br>Industrial: 4%<br>Plastic/metal: 1% |
| **Emission factors** | Emission factors were obtained from the IPCC Emissions Factor Database (2015) and DEFRA (2014). All estimates of emissions from biomass were based on the default value of fraction of non-renewable biomass for Rwanda, as calculated in CDM (2010) – i.e. 98%. | |

# References


Bazimenyera JD, Qiang F, Ntakirutimana T. 2012a. Assessment of the characteristics of Nyanza Landfill leachate, Rwanda. Advanced Materials Research (Trans Tech Publications). 599 618-621.

BAZIMENYERA, JD., Qiang, F., & Karangwa, A. (2012b). Solid waste management in Kigali City, Rwanda. East African Journal of Science and Technology, 2, 46-58.

BNEF. 2015. Bloomberg Rwandan Electricity Generation Database. Bloomberg New Energy Finance, London.

Businge J. 2015. Fuel dealers or profiteers? The Independent. Published 18 January 2015. Available from: http://www.independent.co.ug/business/business-news/9647-fuel-dealers-or-profiteers- [retrieved 10/06/2015]

CDM. 2010. Default values of fraction of non-renewable biomass. United Nations Framework Convention on Climate Change Clean Development Mechanism. Available from: https://cdm.unfccc.int/DNA/fNRB/index.html [retrieved 21/08/2015]

CIA. 2005. World Factbook: Rwanda. Central Intelligence Agency. Available from: http://www.laister.eu/print/rw.html [retrieved 06/07/2015]

City of Kigali. 2001. Kigali Economic Development Strategy. Kigali Institute of Science, Technology and Management. Available from: http://repositories.lib.utexas.edu/bitstream/handle/2152/5397/2692.pdf

City of Kigali. 2013. Kigali City Analysis Benchmarking and Vision Report. Available from: http://www.masterplan2013.kigalicity.gov.rw/downloads/Docs/RWF1101_02_Kigali%20City_Analysis%20Benchmarking%20and%20Vision%20Report_03062013-s.pdf [retrieved 28/05/2015]

DEFRA. 2014. 2014 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors. Department of Energy, Food and Rural Affairs. United Kingdom. Available from: http://www.ukconversionfactorscarbonsmart.co.uk/documents/2014%20Emission%20Factor%20Methodology%20Paper_FINAL-4Jul14.pdf [retrieved 19/08/2015]

Downing T, Watkiss P, Dyszynski J, Butterfield R, Devisscher T, Pye S, et al... 2009. Economics of Climate Change in Rwanda. Stockholm Environment Institute. Available from: http://www.sei-international.org/publications?pid=1579 [retrieved 05/06/2015]

Drigo R, Munyehirwe A, Nzabanita V, Munyampundu A. 2013. Update and upgrade of WISDOM Rwanda and Woodfuels value chain analysis as a basis for the Rwanda Supply Master Plan for fuelwood and charcoal. Rwanda Natural Resources Authority (RNRA) and the Department of Forestry and Nature Conservation (DFNC). Available from: http://www.btcctb.org/files/web/project/publications/Rwanda%20Supply%20Master%20Plan%20for%20fuelwood%20and%20charcoal.pdf [retrieved 21/08/2015]

Gathani S, Stoelinga D. 2013. Understanding Rwanda's Agribusinesses and Manufacturing Sectors. Laterite and International Growth Centre.

Henninger SM. 2013. When Air Quality Becomes Deleterious—A Case Study for Kigali, Rwanda. Journal of Environmental Protection. 4, 1-7.

GEF. 2005. Sustainable Energy Development Project: Financing Plan. Global Environment Facility. Available from: http://documents.worldbank.org/curated/en/2014/07/19904831/rwanda-sustainable-energy-development-project-rwanda-sustainable-energy-development-project [retrieved 06/06/2015]

IPCC. 2015. Emissions Factor Database. Intergovernmental Panel on Climate Change. Available from: http://www.ipcc-nggip.iges.or.jp/EFDB/main.php [retrieved 19/08/2015]

JICA. 2015. The Project for Preparation of Electricity Development Plan for Sustainable Geothermal Energy Development in Rwanda. Japanese International Cooperation Agency. Prepared for the Ministry for Infrastructure. [retrieved 30/03/2015]

Kazoora C. 2010. Final Report on Four Economic Instruments. UNDP-UNEP Poverty Environment Initiative. Available from: http://www.unpei.org/sites/default/files/e_library_documents/rwanda-finalreport-ECONOMICINSTRUMENTS.pdf [retrieved 21/08/2015]

KCC. 2011. About Kigali: City of Kigali a gateway to Rwanda. Kigali City Council. Available from: http://www. kigalicity.gov.rw/spip.php?article109 [retrieved on 2/10/2015].

Lahmeyer International, Electrogaz. 2004. Analysis and Projection of Rwanda's Electricity Demand. Available from: http://www.devpartners.gov.rw/fileadmin/templates/docs/EDPRS/Key%20Analytical%20Studies/Sectoral%20Studies/Energy_Demand_Analysis_%26_Projection_2004.pdf [retrieved 15/08/2015]

MARGE. 2009a. Rwanda: Biomass Energy Strategy: Volume 2: Background and Analysis. European Union Energy Initiative on behalf of Ministry of Infrastructure, Ministry of Environment and Natural Resources. Available from: http://cleancookstoves.org/resources_files/best-volume-2background.pdf [retrieved 08/06/2015]

MARGE. 2009b. Rwanda: Biomass Energy Strategy: Volume 4: Proposed Strategy. European Union Energy Initiative on behalf of Ministry of Infrastructure, Ministry of Environment and Natural Resources. Available from: http://cleancookstoves.org/resources_files/best-volume-4-proposed.pdf [retrieved 08/06/2015]

MININFRA. 2011. National Energy Policy and Strategy. Ministry of Infrastructure. Available from: https://energypedia.info/images/7/77/ENERGY_POLICY_and_STRATEGY.pdf [retrieved 05/06/2015]

Mukaaya E. 2008. Kerosene prices fall by 3.3 percent. The New Times. Published 17 October 2008. Available from <http://www.newtimes.co.rw/section/article/2008-10-17/40553/>

NISR. 2006. EICV2 Thematic Report: Utilities and Amenities. National Institute of Statistics of Rwanda. Available from: http://www.statistics.gov.rw/survey-period/integrated-household-living-conditions-survey-2-eicv-2 [retrieved 05/06/2015]

NISR. 2011. EICV3 Thematic Report: Utilities and Amenities. National Institute of Statistics of Rwanda. Available from: http://www.statistics.gov.rw/survey-period/integrated-household-living-conditions-survey-3-eicv-3 [retrieved 05/06/2015]

NISR. 2013. Statistical Yearbook 2012. National Institute of Statistics of Rwanda. Kigali. Available from: http://statistics.gov.rw/publications/statistical-yearbook-2012 [retrieved 28/05/2015]

NISR. 2014. Statistical Yearbook 2013. National Institute of Statistics of Rwanda. Kigali. Available from: http://statistics.gov.rw/publications/statistical-yearbook-2013 [retrieved 28/05/2015]

NISR. 2015a. Statistical Yearbook 2014. National Institute of Statistics of Rwanda. Kigali. Available from: http://statistics.gov.rw/publications/statistical-yearbook-2014 [retrieved 28/05/2015]

NISR. 2015b. Rwanda Integrated Households Living Conditions Survey [EICV] 2013/2014: Main Indicators Report. National Institute of Statistics of Rwanda. Available from: http://statistics.gov.rw/publications/main-indicators-report-results-eicv-4 [retrieved 05/06/2015]

Nkurikiyinka J-C. 2008. EAC Strategy to Scale ¬Up Access to Modern Energy Service: Rwanda Country Report and Implementation Workplan. East Africa Community. Available from: http://www.eac.int/energy/index.php?option=com_docman&task=cat_view&gid=52&Itemid=70 [retrieved 08/06/2015]

OANDA. 2015. Historical Exchange Rates. Available from <http://www.oanda.com/currency/historical-rates/> [retrieved 06/07/2015]

REMA. 2014. Rwandan Grid Emissions Factor Stabilized Baseline. Rwandan Environment Management Authority. Kigali. May 20, 2014. Available from: https://cdm.unfccc.int/sunsetcms/storage/contents/stored-file-20140625122845372/Rwanda_GEF_SB_May-14.pdf [retrieved 10/06/2015]

RTDA. 2012. Planning & Design of Public Transport System for Kigali City. Rwandan Transport Development Authority. Available from: http://www.kigalicity.gov.rw/spip.php?article876 [retrieved 09/06/2015]

Safari B. 2010. A review of energy in Rwanda. Renewable and Sustainable Energy Reviews. 14. 524-529

SSI Engineers. 2011a. Revealed Preference Dataset. SSI Engineers. Kigali, Rwanda.

SSI Engineers. 2011b. Development of a Hierarchical Multi-Modal Transport Model: Model Development Task Specific Technical Report. SSI Engineers. Kigali, Rwanda.

UN Data. 2015. Energy Statistics Database: Rwanda. United Nations Statistics Division. Available from: http://data.un.org/Explorer.aspx?d=UNSD [retrieved 06/07/2015]

UN-Habitat 2008. "UN-Habitat Scroll of Honour Award". Available from: http://mirror.unhabitat.org/content.asp?typeid=19&catid=827&cid=6586 [retrieved 12/10/2015]

UNEP. 2013. Rwanda: State of Environment and Outlook Report 2013. Available from http://na.unep.net/siouxfalls/publications/Kigali_SOE.pdf [retrieved 28/05/2015]

World Bank. 2015a. Consumer price index (2010 = 100). Available from: http://data.worldbank.org/indicator/FP.CPI.TOTL [retrieved 06/07/2015]

World Bank. 2015b. Pump Price for Gasoline (US$ per litre). Available from: http://data.worldbank.org/indicator/EP.PMP.SGAS.CD/countries?page=2 [retrieved 21/05/2015]

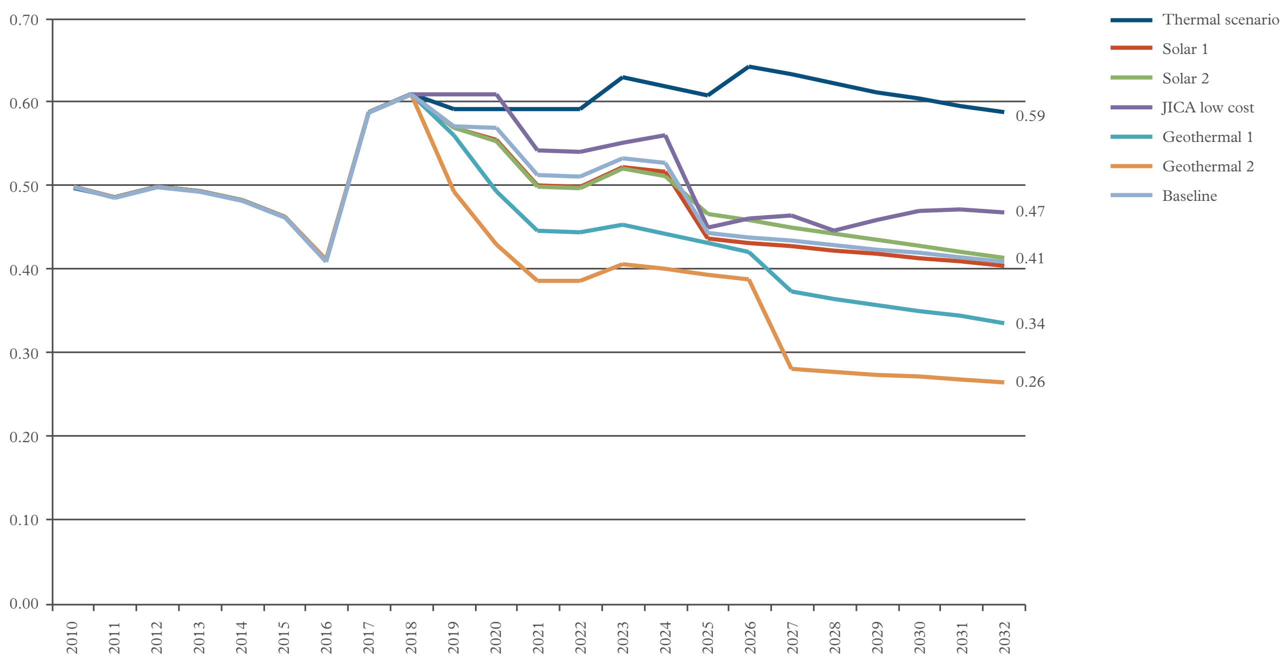



# Appendix C. Data Sources, Methods and Assumptions for the Options Appraisal

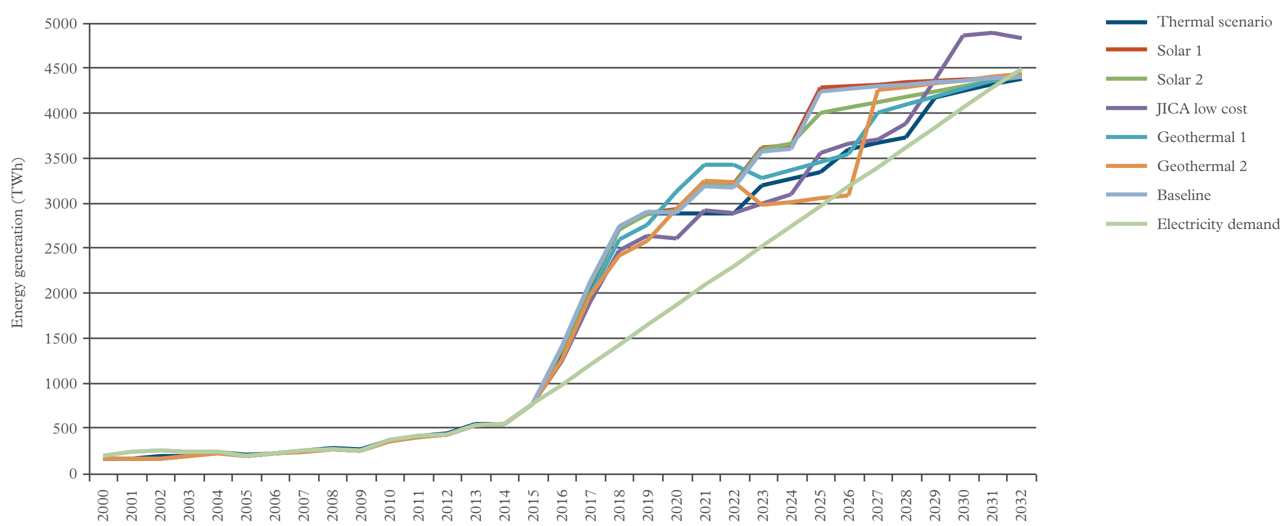
## Electricity sector

Scenarios are compared to the 'baseline scenario', which was developed from planned investments and the 'low cost scenario' developed by JICA (2015). Through an iterative participatory process these scenarios were refined to outline six alternative pathways for the electricity sector through 2032 in Rwanda. Each scenario produces a minimum of 4500 GWh in 2032 with 1036 MW of dispatchable supply.

### Figure 24: Emissions factor for each scenario, 2015-2032.




### Figure 25: Energy generation (TWh) under each scenario between 2000 and 2032.




For details of energy generation in 2032 under each scenario, see Table 1.

Table 13: Key technology-specific values (2015-2032 averages).

| Technology | Capacity factor | Capital cost (USD million/MW) | Operating and maintenance costs (cents per KWh) |
|---|---|---|---|
| **Hydropower** | 0.75 | 4.00 | 0.80 |
| **Methane gas** | 0.85 | 3.70 | 8.80 |
| **Solar** | 0.16 | 3.00 | 0.00 |
| **Peat** | 0.42 | 3.20 | 5.50 |
| **Geothermal** | 0.85 | 3.00 | 0.50 |
| **Diesel** | 0.61 | 3.00 | 27.00 |
| **Imports** | – | case specific | 7.50 |

Sources: BNEF (2015), AFDB (2013), MINIFRA (2011), REMA (2014), JICA (2015) and stakeholder consultation.

## Residential sector

| Measure | Data sources, methods, and assumptions |
|---|---|
| **Building energy efficiency – training workshops** | We assume there are no additional costs associated with constructing green residential buildings in Kigali. Passive cooling levels can be achieved by, for example, optimising building orientation or window-to-wall ratios). Kigali City Council currently holds training workshops with architects, construction firms and other private sector organisations at RWF 11 million per workshop.<br><br>The economic savings are based on avoided investment in and energy consumption by air conditioners. Air conditioners in this model cost RWF 495,000, based on prices in Rwanda's online marketplace, Kaymu (2015). This is a 3.5kW model, so would consume 700kWh per year if we assume 2 hours of use per day 100 days per year. We assume that conducting one workshop per year will prevent purchase of air conditioners by 1% of households in Kigali (roughly 3,000 air conditioners by 2032). These estimates reflect low levels of interest in purchasing an air conditioner, due to Rwanda's temperate climate.<br><br>For reference, Seoul in Korea has a similar climate to Kigali for six months of the year with an average high of 29.5°C (KMA, 2015) (the city experiences much colder winters). Between 2000 and 2010, the number of air conditioners in Seoul increased from <0.1 to 0.5 per household (Kim et al., 2013), as average per capita GDP in the country increased from $11,948 to $22,151 (World Bank, 2015) (per capita GDP in Seoul would have been significantly higher). Per capita GDP in Rwanda in 2013 was $639 (World Bank, 2015). Therefore, even with 9% annual growth, Rwanda's income will be less than a third of South Korea's and air conditioner ownership will be commensurately less. |
| **Improved cookstoves** | In CDM baseline calculations for efficient cookstoves, Hogarth (2011) calculates that the quantity of woody biomass saved per year by an improved cookstove (SAVE80 model) is 0.495 tonnes and that 88.6% of the woody biomass saved is from non-renewable sources. The carbon offset per stove is therefore 0.47t$CO_2$-e per year. An improved SAVE80 cookstove costs US$100 and has a lifespan of 10 years (Hogarth, 2011).<br><br>The quantity of woody biomass saved per year by an improved cookstove (JICO model) is 0.421 tonnes and that 88.6% of the woody biomass saved is from non-renewable sources. The carbon offset per stove is therefore 0.4t$CO_2$-e per year. An improved JICO cookstove costs US$10 and has a lifespan of 4 years (Hogarth, 2011). |



Continued

| Measure | Data sources, methods, and assumptions |
|---|---|
| **More efficient lighting** | Incandescent bulbs have an average input power of 60W, a life span of 1,200 hours and cost RWF 630.62. Compact fluorescent lamps (CFL) have an average input power of 14W, a life span of 10,000 hours and cost RWF 2,541. Light emitting diodes (LED) have an average input power of 10W, a life span of 50,000 hours and cost RWF 22,671 (Fabien, 2013). The price of a subsidised CFL bulb is RWF 200 (World Bank, 2014).<br><br>Based on the Residential Customer Lighting Survey of Kigali (MININFRA, 2008), the average household has approximately six light bulbs. For future growth, we assumed that social housing would have 2 bulbs, affordable housing would have 4 bulbs, mid-range housing would have 10 bulbs and premium housing would have 20 bulbs per household. These are conservative estimates, so we understate the potential carbon savings.<br><br>800,000 CFL bulbs were deployed by the end of 2012 as part of the Rwanda Electrogaz Compact Fluorescent Lamp (CFL) Distribution Project (Sarkar, 2008). We have assumed that CFL bulbs have not achieved further market penetration due to their additional capital costs, but that incandescent bulbs would be entirely replaced with CFL bulbs by 2030 without policy interventions.<br><br>We assume 0% LED light bulbs in Kigali in 2015. |
| **Replacing charcoal cookstoves with LPG cookstoves** | Charcoal stoves consume 194kg/pp/pa (Drigo et al., 2013) while LPG stoves consume 22kg/pp/pa (IEA, 2006). An improved cookstove costs USD10 (Hogarth, 2011), while experts in the workshops estimated that a used LPG stove can be purchased for RWF 150,000. |
| **Solar home systems** | A 30Wp solar home system requires a down payment of US$27 and then monthly payments of US$10 for 36 months. A 80Wp solar home system requires a down payment of US$45 and then monthly payments of US$22 for 36 months. A 120Wp solar home system requires a down payment of US$57 and then monthly payments of US$34 for 36 months. A 200Wp solar home system requires a down payment of US$86 and then monthly payments of US$47 for 36 months (Sprenger, 2013).<br><br>All solar home systems are estimated to have a conversion efficiency of 17% and life span of 20 years. We consider three levels of deployment: 5,000, 10,000 and 15,000 solar home systems deployed by 2032. These low levels reflect the fact that most households that can afford solar power have reasonably reliable access to grid electricity. Under these three levels of deployment, total installed capacity in 2032 would range from 150kW (i.e. 5,000 30Wp solar home systems deployed) to 3MW (i.e. 15,000 120Wp solar panels deployed). |
| **Solar lamps** | Solar lamps replace kerosene lamps. A household using kerosene lamps consumes approximately 1L per week. The kerosene lamps cost US$1. Solar lamps cost US$30 and have a lifespan of 5 years (Disch andBronckaers, 2012). |

Continued

| Measure | Data sources, methods, and assumptions |
|---|---|
| **Solar water heaters** | A 200L solar water heater has an average cost of US$1,300 and a 300L solar water heater has an average cost of US$1,600 (REG, 2014). REG estimates that installing 12,000 solar water heaters would save 23,328MWh per year (REG, 2014). Assuming equal deployment of 200L and 300L solar water heaters, we therefore calculate that a 200L solar water heater would save 1,555.2kWh per year and a 300L solar water heater would save 2,332.8kWh per year.<br><br>The subsidy for a 200L solar water heater is RWF 186,000 and the subsidy for a 300L solar water heater is RWF 279,000. In both cases, this is less an application fee of RWF 30,000 (REG, 2014).<br><br>Solar water heaters have a lifespan of 15-20 years. We have conservatively used 15 years in this analysis. We consider three levels of deployment: 10,000, 20,000 and 30,000 solar water heaters deployed by 2032. Under these three levels of deployment, total installed capacity in 2032 would range from 200,000L (i.e. 10,000 200L solar water heaters deployed) to 900,000L (i.e. 30,000 230L solar water heaters deployed). |

## Commercial and Public Sector

| Measure | Data sources, methods, and assumptions |
|---|---|
| **Building energy efficiency standards** | The economic savings are based on avoided investment in and energy consumption by air conditioners. Air conditioners in this model cost RWF 707,143. This assumes a 5kW model suitable for commercial and public buildings has a proportionate cost to the 3.5kW model suitable for residential buildings, and available in Rwanda's online marketplace, Kaymu (2015). We assume 3 hours of use per day 100 days per year. The total number of air conditioners by 2032 is based on cooling needs of 5W/m2. This is a very low rate, based on the fact that Kigali's comfortable climate leads to low demand for heating and cooling. Total amount of retail, office and hotel floor space is based on projections from the City of Kigali's (2013) Master Plan.<br><br>Data on the incremental costs of improving building energy efficiency are taken from Ürge-Vorsatz et al. (2015), which finds that new commercial and public buildings in a moderate efficiency scenario cost USD 886/m2, while advanced new commercial and public buildings would cost USD 1,217/m2. These are sub-Saharan Africa wide estimates, refined by climate zone: we consider Rwanda to fall into the zone of "Only cooling (low and moderate cooling demand)". |

| Measure | Data sources, methods, and assumptions |
|---|---|
| **More efficient lighting** | Net present value and carbon savings are calculated using the following data from Fabien (2013) |

| Light bulb type | Input power (W) | Life span (hours) | Cost (RWF) |
|---|---|---|---|
| **Incandescent** | 60 | 1,200 | 630.62 |
| **Compact fluorescent lamp (CFL)** | 14 | 10,000 | 2,541 |
| **Light emitting diode (LED)** | 10 | 50,000 | 22,671 |
| **CFL tube 1** | 25 | 8,000 | 4,109 |
| **LED tube 1** | 8 | 40,000 | 44,521 |
| **CFL tube 2** | 40 | 8,000 | 4,109 |
| **LED tube 2** | 23 | 40,000 | 44,521 |

| Measure | Data sources, methods, and assumptions |
|---|---|
| **Solar panels** | Two sizes of solar panels were modelled – 1.5kWp and 2.5kWp – based on the range provided in GTZ's analysis of the solar market in Rwanda (Kirai et al., 2009). Under the three different levels of deployment modelled, total installed capacity would range from 1.5MW (i.e. 1,000 1.5kWp solar panels deployed) to 7.5MW (3,000 2.5 kWp solar panels deployed).<br><br>A 250Wp solar panel cost RWF 276,000 (US$ 381.57) on kaymu.rw (2015b) as of 07/07/2015. This was used as the standard price for 250W, i.e. a 1.5kWp solar panel cost six times as much and a 2.5kWp solar panel cost ten times as much. Solar panels are assumed to have a conversion efficiency of 14.5% and life span of 20 years. |
| **Solar water heaters** | Scope for substantial adoption in the hospitality industry (for example, hotels and restaurants): we have modelled deployment rates of 1000, 2000 and 3000 to 2032.<br><br>A 300L solar water heater has an average cost of US$1,600 (REG, 2014). The subsidy for a 300L solar water heater is RWF 279,000, less an application fee of RWF 30,000 (REG, 2014).<br><br>REG estimates that installing 12,000 solar water heaters would save 23,328MWh per year (REG, 2014). Assuming equal deployment of 200L and 300L solar water heaters, we therefore calculate that a 200L solar water heater would save 1,555.2kWh per year and a 300L solar water heater would save 2,332.8kWh per year. In the commercial sector, we have assumed that only 300L solar water heaters would be deployed.<br><br>Solar water heaters have a lifespan of 15-20 years. We have conservatively used 15 years in this analysis. |

Continued

| Measure | Data sources, methods, and assumptions |
|---|---|
| **Street lighting: replacing high pressure sodium bulbs with LED bulbs** | There are three levels of power required in Rwandan street lights (City of Kigali, 2013b):<br>• 15 poles with low wattage: 150W bulbs will be replaced with 80W LED bulbs<br>• 6251 poles with medium wattage: 250W bulbs will be replaced with 120W LED bulbs<br>• 800 poles with high wattage: 400W bulbs will be replaced with 200W LED bulbs<br>Traditional sodium high pressure bulbs have a lifespan of 10,000 hours. LED bulbs have a lifespan of 50,000 hours. Street lights are turned on for 12 hours per night (there are 11.4 hours of darkness in Kigali) (City of Kigali, 2013b). Fixtures and lamps for high pressure sodium bulbs cost USD 250, with an annual replacement cost of USD 14.4. Fixtures and lamps for LED bulbs cost USD 475, with an annual replacement cost of USD 7.2 (Silsby, 2013). |

## Transport sector

| Measure | Data sources, methods, and assumptions |
|---|---|
| **Bike lane Investments** | We model the impact of building 40km of protected cycle-ways in Kigali. Capital costs and maintenance costs are estimated using the Bogota Cicloruta as a case study (C40, 2013) and the 'Share the Road' cycling project in Nairobi UNEP (2015). Impacts on transport modal share are estimated from a combination of focus groups, consultation with members of the transport industry and the C40 Bogota case study (2013), Sietchiping (2012) and Jennings (2014). The location of bike lanes is informed by MINIFRA (2011a). |
| **Parking meters in CBD** | Under this scenario parking meters are deployed over 10km of roads in the central business district. 35 meters are installed per km and operate 12 hours per day. Cost for installation and maintenance are drawn from Litman (2009). The occupied rate (50%) and cost per hour (100 RWF) were determined by consultation. The effect of parking meters on travel to the city centre was informed by Litman (2009), with adjustments made from discussions at workshops. |
| **Import age restrictions (<15, <10, Euro IV)** | These measures assess the impact from banning the import of vehicles older than a specified age. Analysis of the impact drew heavily from previous work completed by the Rwandan Transport Development Agency (RTDA) who provided data on vehicle imports, prices, import taxes, vehicle efficiencies and the elasticity of demand for vehicles in Rwanda. When modeled from the perspective of the government, lost revenue from vehicles not imported are compared against additional revenue from purchases of younger vehicles. From the perspective of the general public the cost of purchasing more expensive vehicles and the cost of additional motos and buses to accommodate travel needs is compared against the fuel savings from more efficient vehicles and fewer total imported vehicles. In both cases the strong assumption is made that total trips within Kigali remain constant. Further, the assumption is made that after three years the total number of vehicles purchased returns to the baseline number as the elasticities provided by RTDA are not viable more than three years into the future. |



Continued

| Measure | Data sources, methods, and assumptions |
|---|---|
| **BRT lines (1 and 2)** | These measures model the impact of two planned bus rapid transit lines: One from the central business district to Rusororo, a second from the central business district to Gahanga. Key data for these measures, including the total cost of building the BRTs, operating days, operating hours and tariffs are drawn from the Kigali Masterplan (2013), MINIFRA (2011b) and RTDA (2012). The fuel efficiency of vehicles is assumed to be 2.5 km/l. Fuel costs are assumed to be 35% of total operating costs based on SSI (2011a, b). The number of trips per hour is estimated to be 6000 for BRT line 1 and 6500 for BRT line 2 based on consultation. |
| **Electric motorbikes** | In this scenario electric motorbikes grow to 5% of total passenger trips by 2032 by taking modal share from moto transport. Electric bike costs, efficiencies, annual kilometres and lifetimes were provided by Ampersand (2015). The scenario was developed through consultation with members of industry. Under the public scenario investment costs are the cost of electric bikes and electricity while savings are fuel not spent and conventional motorbikes not purchased. Under the private scenario individuals are required to finance their electric bike at an annual interest rate of 34.5% over two years but save on fuel expenditure. |
| **Bus network expansion (standard buses and Euro IV buses)** | We model the impact of doubling the existing fleet of mini and large buses in the metropolitan Kigali area by 2032. Capital cost, operating costs, fuel efficiencies, operating days, operating hours, vehicle lifespans and travel tariffs are drawn from MINIFRA (2012) and City of Kigali (2013). Minor changes to these data were made during stakeholder workshops. It is assumed that bus occupancy remains constant through 2032. Under the Euro IV scenario it is assumed that buses operate at 20% higher efficiency and cost 40% more than conventional buses. All other variables are the same. Under the Euro IV scenario it is assumed that current programs to train mechanics to service Euro IV vehicles accelerates over the period to 2032. |

## Waste sector

| Measure | Data sources, methods, and assumptions |
|---|---|
| **Landfill gas utilisation** | In this measure we have assumed 75% landfill gas collection efficiency (Yang, 2010; EPA 2013) and a 10% oxidation factor due to landfill cover (Manfredi et al., 2009). Electricity generation from LFG and $CO_2$-e carbon emission reductions from displaced energy are calculated based on academic literature (European Communities, 2001; IPCC, 2006). 10% of the electricity generated is used on site. Capital and operational costs are based on landfill gas utilisation case studies in developing countries (WEC, 2013; CDM, 2012; IRENA, 2012; and World Bank, 1999). Revenue from generated electricity is assumed to be 10 US cents/Kwh based on consultation. |
| **Landfill gas flaring** | Flaring efficiencies are based on case studies of CDM projects operating in Ghana and Indonesia (CDM, 2012; and Yang, 2010). Global assumptions based on landfill characteristics (EPA, 2013) and academic literature (Manfredi et al., 2009) are also considered. The CoK targets to have 70% of collected waste landfilled by 2025, and is putting in place strict regulation on Landfill management to be enforced by RURA and REMA.<br><br>Capital and operational costs are based on several CDM projects and case studies of costs for LFG flaring projects (CDM, 2009; CDM, 2012; IRENA, 2012; and World Bank 1999). $CO_2$-e savings are calculated based on 20% (Yang, 2010) and 65% (EPA, 2013) gas collection efficiencies. Oxidation factor due to landfill cover is taken to be 10%. |
| **Centralised composting** | Food waste makes up more than 67% of total organic waste generated in Kigali, with garden and wood waste making up 7% and 3% respectively (REMA, 2013). Measures targeted at food waste could therefore have a significant impact on emissions reduction efforts.<br><br>This measure assumes a windrow plant for central composting, common in a developing country context. 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 food waste. Participation rates of 20% and 30% of the target population are based on WRAP (2009, 2011) case studies, as well as from discussions with stakeholders operating in the sector.<br><br>Capital and operational costs are based on CDM composting projects in Uganda and Nigeria (CDM, 2014a) and comparative studies on composting (Hareen, 2009). The assessment considers a revenue source from the sale of compost, with current prices obtained from local stakeholders involved in composting. |
| **Home composting** | Home composting assumes aerobic biological treatment of organic waste within the household. Household participation rates of 15% and 30% are conservative estimates based on consultations with local stakeholders and CoK targets for waste management (CoK, 2012). Potential yield factors are drawn from WRAP (2009, 2011) case studies. The carbon emissions savings calculations are based on IPCC (2006) and European Communities (2001). The costs of home composting are assumed to come from household level sensitisation campaigns. The containers used in composting are assumed to be recycled from other household use.<br>No revenue stream is considered for home composting. |



Continued

| Measure | Data sources, methods, and assumptions |
|---|---|
| **Energy from waste through Anaerobic Digestion** | Savings from this measure are calculated assuming a 15MW electricity production power plant. It is based on an electricity only recovery scenario.Calculations of electricity, heat generation potentials and carbon emissions savings from energy displaced are based on IPCC (2006) and European Communities (2001). Capital and operational costs are based on case studies in Europe (IRENA 2012). Emissions resulting from the construction of the plant are derived from Brogaard (2013). |
| **Recycling program** | This measure considers the recycling of paper and plastic.<br>Waste is source separated but goes through additional sorting at the recycling facility. Additional emissions from extra transportation of recycled materials are accounted for. The yield of recycling material is based on consultations with local stakeholders. 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 (WRAP, 2013) |
| **Biogas production** | This measure assumes emissions savings from the use of organic waste for biogas production by commercial institutions like restaurants, hotels, hospitals, boarding schools and prisons. Carbon emission estimations are based on IPCC (2006) and European Communities (2001). A conservative yield of 10% of commercial food waste is targeted. Biodigester construction costs are derived from SNV Netherlands Development Organisations study on financing of Domestic Biogas plants in Rwanda (2008) and Experiences from India (Agrahari &Tiwari, 2013). Gas produced is assumed to be used in-house and savings are derived from avoided costs had the gas been purchased. |

# References


AfDB. 2013. Rwanda Energy Sector Review and Action Plan. African Development Bank. Available from: http://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Rwanda_-_Energy_Sector_Review_and_Action_Plan.pdf [retrieved 06/09/2015]

Agrahari RP, Tiwari GN. 2013. The Production of Biogas Using Kitchen Waste. International Journal of Energy Science. 3(6) 408-413

Bloomberg. 2015. Rwandan Electricity Generation Database., 2015. 15/06/2015.

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 [retrieved 28/11/2015]

CDM. 2009. Durban Landfill-Gas Biasar Road. United Nations Framework Convention on Climate Change. Clean Development Mechanism. Available from: http://cdm.unfccc.int/filestorage/M/L/N/MLNVZQAWH8REBSD0CTUO26JIG9FKP7/Revised%20final%20PDD.pdf?t=Qkt8bnJvdWlhfDDx1ZQJaFrSewHjaY91US9y [retrieved 05/07/2015]

CDM. 2012. Oti Landfill Gas Capture, Flaring and Utilization at Kumasi (Ghana). United Nations Framework Convention on Climate Change. Clean Development Mechanism. Available from: https://cdm.unfccc.int/filestorage/A/I/E/AIE47N59BTFQYGOD2RXS0V3KZPL6CH/CPA-DD.pdf?t=a3J8bnM1bWZufDA_Qw0A8tZso_KYm7jZF2Sp [retrieved 05/07/2015]

CDM. 2014. CDM Methodology Booklet. United Nations Framework Convention on Climate Change. Clean Development Mechanism. Available from:https://cdm.unfccc.int/me thodologies/documentation/meth_booklet.pdf [retrieve 05/07/2015]

CDM. 2014a. Uganda Municipal Waste Compost Programme. United Nations Framework Convention on Climate Change. Clean Development Mechanism. Available from: https://cdm.unfccc.int/ProgrammeOfActivities/poa_db/JL4B8R2DKF90NE6YXCVOQ3MWSGT5UA/view [retrieved 05/07/2015]

City of Kigali and BTC Rwanda. 2012. Data collection and analysis on Solid Waste Management in the City of Kigali. City of Kigali.

City of Kigali. 2013. Kigali City Analysis Benchmarking and Vision Report. Available from: http://www.masterplan2013.kigalicity.gov.rw/downloads/Docs/RWF1101_02_Kigali%20City_Analysis%20Benchmarking%20and%20Vision%20Report_03062013-s.pdf [retrieved 28/05/2015]

City of Kigali. 2011. Kigali Housing Market: Investor Brochure. Available from: http://www.rdb.rw/uploads/tx_sbdownloader/KCC_Housing_Study.pdf [retrieved 28/05/2015]

City of Kigali. 2013. Request for expression of interest for replacement of sodium high pressure bulbs with the energy efficient light emitting diode on the existing street lights on the urban roads of the City of Kigali. Available from: http://www.kigalicity.gov.rw/IMG/pdf/Expression_of_Interest_-_Public_Lights-_a_draft.pdf [retrieved 21/08/2015]

Disch D, Bronckaers J. 2012. An analysis of the off-grid lighting market in Rwanda: sales, distribution and marketing. Global Village Energy Partnership. Available from: http://www.gvepinternational.org/sites/default/files/rwanda-solar-study-v1.6_small4.pdf [retrieved 03/07/2015]

EPA. 2013. Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Municipal Solid Waste Landfills. United States Environmental Protection Agency. Available from: http://www3.epa.gov/nsr/ghgdocs/landfills.pdf [retrieved 15/10/2015]

European Communities (2001) Waste Management Options and Climate Change. Available from: http://ec.europa.eu/environment/waste/studies/pdf/climate_change.pdf [retrieved 29/10/2015]

Fabien M. 2013. Application of LED type lamps in domestic and public utilities and gain capabilities to run new small investments in Rwanda. Engineering. 5 775-778 doi: 10.4236/eng.2013.510093

Hareem R V, Nikolas J, Morton B. 2009. Large Scale Aerobic Composting of Source Separated Organic Wastes: A Comparative Study of Environmental Impacts, Costs, and Contextual Effects. Department of Earth and Environmental Engineering, Columbia University.

Hogarth R. 2011. "Finance Sector Working Paper". Smith School of Enterprise and the Environment, University of Oxford. Supplement to Green Growth and Climate Resilience: National Strategy for Climate Change and Low Carbon Development. Available from: http://rema.gov.rw/climateportal/IMG/pdf/finance-swp-final_proofed-2.pdf [retrieved 14/06/2015]

IEA. 2006. World Energy Outlook 2006: Chapter 15: Energy for Cooking in Developing Countries. International Energy Agency. Available from: https://www.iea.org/publications/freepublications/publication/cooking.pdf [retrieved 19/08/2015

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Volume 5: Waste. Intergovernmental Panel on Climate Change. Available from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf . [retrieved 30/10/2015]

IRENA. 2012. Renewable Energy Technologies: Cost Analysis Series. International Renewable Energy Agency. Available from: http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf [retrieved 07/05/2015]

Jennings G. 2014. Finding our balance: Considering the opportunities for public bicycle systems in Cape Town, South Africa. Research in Transportation Business & Management. 15 6-14 doi:10.1016/j.rtbm.2014.09.001

JICA. 2015. The Project for Preparation of Electricity Development Plan for Sustainable Geothermal Energy Development in Rwanda. Prepared for the Ministry for Infrastructure.

Kaymu. 2015a. LG air conditioner. Available from: http://www.kaymu.rw/lg-air-conditioner-39037.html [retrieved 07/07/2015]

Kaymu. 2015b. Solar Panel 250w/24v. Available from: http://www.kaymu.rw/solar-panel-250w-24v-51634.html [retrieved 07/07/2015]

Kim S, Oguchi M, Yoshida A, Terazono A. 2013. Estimating the amount of WEEE generated in South Korea by using the population balance model. Waste Management. 33(2) 474-483 doi:10.1016/j.wasman.2012.07.011

Kirai P, Saini A, Hankins M. 2009. Target Market Analysis: The Solar Energy Market in Rwanda. Deutsche Gesellschaft für technische Zusammenarbeit (GTZ) GmbH. Available from: https://www.giz.de/fachexpertise/downloads/gtz2009-en-targetmarketanalysis-solar-rwanda.pdf [retrieved 07/07/2015]

Litman, T. 2009. Transportation cost and benefit analysis. Victoria Transport Policy Institute, 31.

Manfredi S, Scharff H M, Tonini D, Christensen T H. 2009. Landfilling of Waste: Accounting of Greenhouse Gases and Global Warming Contributions. Waste Management & Research. 27 825–836. DOI: 10.1177/0734242X09348529

MININFRA. 2008. Residential Customer Lighting Survey of Kigali. Ministry of Infrastructure. Kigali. Available from: https://www.esmap.org/sites/esmap.org/files/27.%20Rwanda_BASELI NE_SURVEY_FINAL_REPORT.pdf [retrieved 05/07/2015]

MINIFRA. 2011a. Concept Report on Development of Walking and Cycling Facilities for Urban and Semi-Urban on Classified National Road Network of Rwanda. Ministry for Infrastructure.

MINIFRA. 2011b. Final Draft on Public Transport Policy and Strategy for Rwanda. Ministry for Infrastructure.

REG. 2014. Residential Solar Water Heating Program. Rwanda Energy Group (REG), Rwanda Utilities Regulatory Authority (RURA). Available from: http://www.reg.rw/images/pdf/Description%20of%20SolaRwanda%20Program%20Updated%202014%2002%2011.pdf [retrieved 10/06/2015]

REMA. 2014. Rwandan Grid Emissions Factor Stabilized Baseline. Rwandan Environment Management Authority. Kigali. Available from: https://cdm.unfccc.int/filestorage/e/x/t/extfile-20140625122845772-Rwanda_GEF_SB_May-14.pdf/Rwanda_GEF_SB_May-14.pdf?t=WmF8bnc5ajVnfDB94MhmeND8ho-cuOLYzYvk [retrieved 20/05/2015]

RTDA. 2012. Planning & Design of Public Transport System for Kigali City. Rwandan Transport Development Authority. Available from: http://www.mininfra.gov. rw/uploads/media/Public_Transport_Policy_and_strategy_for_Rwanda_02.pdf [retrieved: 05/06/2015]

Sarkar A. 2008. Large Scale CFL Deployment Programs; Mainstreaming Carbon Finance and Clean Development Mechanism. World Bank. Available from: http://www.energyrating.gov.au/wp-content/uploads/Energy_Rating_Documents/Library/Lighting/Lighting/2008-phase-out-session4-sarkar.pdf [retrieved 11/07/2015]


Continued


Silsby SL. 2013. HPS to LED Conversion – A City of Phoenix Experience. City of Phoenix. Available from: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/silsby_msslc-phoenix2013.pdf [retrieved 21/08/2015]

Sietchiping R, Permezel MJ, Ngomsi C. 2012. Transport and mobility in sub-Saharan African cities: An overview of practices, lessons and options for improvements. Cities. 29(3) 183-189.

SNV. 2008. Financing of Domestic Biogas Plants (Rwanda). Netherlands Development Organisation. Available from: http://www.snvworld.org/fr/publications/financing-of-domestic-biogas-plants-3 [retrieved 29/10/2015]

Sprenger R. 2013. Mobile Enabled Offgrid Electrification. Mobisol GmbH. Available from: https://www.giz.de/fachexpertise/downloads/2013-de-pep-fachveranstaltung-direktvermarktung-sprenger.pdf [retrieved 10/06/2015]

SSI Engineers. 2011a. Revealed Preference Dataset. SSI Engineers.

SSI Engineers. 2011b. Development of a Hierarchical Multi-Modal Transport Model: Model Development Task Specific Technical Report.

UNEP. 2010. Waste and Climate Change: Global Trends and Strategy Framework. United Nations Environmental Programme. Available from: http://www.unep.or.jp/ietc/Pub lications/spc/Waste&ClimateChange/Waste&ClimateChange.pdf [retrieved 05/06/2015]

UNEP. 2015. Share the Road: Increased investment in Walking and Cycling Infrastructure. Available from: http://www.unep.org/transport/sharetheroad/ News_info/news_archive_details.asp [retrieved 05/07/2015]

World Bank. 2008. Low-carbon Energy Projects for Development in Sub-Saharan Africa. Available from: https://wbcarbonfinance.org/docs/Main_Report_Low_Carbon_Energy_projects_for_Development_of_Sub_Saharan_Africa_8-18-08.pdf [retrieved 07/05/2015]

World Bank. 1999. Observations of Solid Waste Landfills in Developing Countries: Africa, Asia, and Latin America. Available from: http://www.worldbank.org/urban/solid_wm/ erm/CWG%20folder/uwp3.pdf [retrieved 07/05/2015]

World Bank. 2015. GDP per capita (current US$). Available from: http://data.worldbank.org/indicator/NY.GDP.PCAP.CD?page=2

World Bank. 2014. Raising Awareness of Energy Efficient Light Bulbs Pays off in Rwanda. Available from: http://www.worldbank.org/en/news/feature/2014/11/06/raising-awareness-energy-efficient-light-bulbs-pays-off-rwanda [retrieved 11/07/2015]

WEC. 2013. World Energy Perspectives: Cost of Energy Technologies. World Energy Council. Available at: http://www.worldenergy.org/wp-content/uploads/2013/09/WEC_J114 3_CostofTECHNOLOGIES [retrieved 07/05/2015]

# Appendix D. League Table of the Most Cost-Effective Measures in Kigali (NPV/tCO2-e)

| Rank: | Sector | Measure: | USD/tCO2-e | RWF/tCO2-e |
|---|---|---|---|---|
| 1 | Residential | Building energy efficiency – training workshops | -1,860 | -1,274,316 |
| 2 | Residential | Replacing kerosene lamps with solar lamps | -1,784 | -1,221,860 |
| 3 | Transport | Parking meters in CBD (public case) | -691 | -480,189 |
| 4 | Transport | Bike lane investments (public case) | -676 | -469,565 |
| 5 | Transport | Electric bike – 5% of trips 2032 (public case) | -650 | -451,672 |
| 6 | Transport | Electric bike – 5% of trips 2032 (private case) | -647 | -449,582 |
| 7 | Commercial and public | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs | -425 | -291,195 |
| 8 | Residential | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs | -425 | -291,195 |
| 9 | Commercial and public | Replacing incandescent light bulbs with compact fluorescent bulbs | -405 | -277,095 |
| 10 | Residential | Replacing incandescent light bulbs with compact fluorescent bulbs | -405 | -277,095 |
| 11 | Transport | Import age restrictions <15 (public case) | -360 | -249,951 |
| 12 | Commercial and public | Street lighting: replacing high pressure sodium bulbs with LED bulbs | -349 | -239,165 |
| 13 | Commercial and public | Replacing incandescent light bulbs with light emitting diodes (LEDs) | -346 | -236,931 |
| 14 | Residential | Replacing incandescent light bulbs with light emitting diodes | -346 | -236,931 |
| 15 | Residential | 200L solar water heaters - with subsidy | -273 | -187,248 |
| 16 | Residential | 200L solar water heaters | -255 | -174,382 |
| 17 | Transport | Import age restrictions <10 (public case) | -234 | -162,478 |
| 18 | Commercial and public | 2.5kWp solar panel | -231 | -158,435 |
| 19 | Commercial and public | 1.5kWp solar panel | -231 | -158,435 |
| 20 | Commercial and public | Replacing compact fluorescent tubes with LED tubes | -192 | -131,834 |

Continued

| Rank: | Sector | Measure: | USD/tCO2-e | RWF/tCO2-e |
|---|---|---|---|---|
| 21 | Transport | Euro IV standards (public case) | -180 | -125,401 |
| 22 | Commercial and public | 300L solar water heater with subsidy | -180 | -123,406 |
| 23 | Residential | 300L solar water heaters - with subsidy | -180 | -123,406 |
| 24 | Commercial and public | 300L solar water heater | -160 | -109,716 |
| 25 | Residential | 300L solar water heaters | -160 | -109,716 |
| 26 | Residential | Improved cookstoves (JICO model) | -113 | -77,128 |
| 27 | Residential | Improved cookstoves (SAVE80 model) | -89 | -60,830 |
| 28 | Transport | Bus network expansion - doubling of 2015 capacity by 2032 (public case) | -71 | -49,006 |
| 29 | Transport | Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (public case) | -70 | -48,563 |
| 30 | Transport | BRT Line 1 - CBD to Rususoro (public case) | -58 | -40,108 |
| 31 | Transport | Bus network expansion - doubling of 2015 capacity by 2032 (private case) | -12 | -8,573 |
| 32 | Transport | BRT Line 2 - CBD to Gahanga (public case) | -7 | -4,538 |
| 33 | Waste | LFG utilisation | -5 | -3,440 |
| 34 | Transport | Parking meters in CBD (private case) | -4 | -2,872 |
| 35 | Waste | Centralised anaerobic digestion to electricity | 0 | -284 |
| 36 | Transport | Import age restrictions <10 (government case) | 0 | 0 |
| 37 | Transport | Euro IV standards (government case) | 0 | 0 |
| 38 | Waste | Home composting (30%) | 1 | 737 |
| 39 | Waste | Home composting (15%) | 1 | 773 |
| 40 | Waste | Landfill gas flaring (65%) | 3 | 1,850 |

Continued

| Rank: | Sector | Measure: | USD/tCO2-e | RWF/tCO2-e |
|---|---|---|---|---|
| 41 | Transport | Import age restrictions <15 (government case) | 3 | 1,847 |
| 42 | Waste | Landfill gas flaring (25%) | 6 | 4,057 |
| 43 | Waste | Recycling (20%) | 7 | 4,927 |
| 44 | Waste | Recycling (40%) | 8 | 5,707 |
| 45 | Waste | Home biogas production | 9 | 6,211 |
| 46 | Commercial and public | Replacing compact fluorescent bulbs with light emitting diodes (LEDs) | 19 | 13,166 |
| 47 | Residential | Replacing compact fluorescent bulbs with light emitting diodes | 19 | 13,166 |
| 48 | Waste | Central composting (19%) | 28 | 18,835 |
| 49 | Waste | Central composting (30%) | 31 | 21,365 |
| 50 | Transport | Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (private case) | 37 | 25,752 |
| 51 | Transport | Bike lane investments (private case) | 56 | 39,158 |
| 52 | Residential | 200W solar home system | 224 | 153,524 |
| 53 | Residential | 80W solar home system | 336 | 229,965 |
| 54 | Residential | 120W solar home system | 350 | 239,779 |
| 55 | Residential | Replacing charcoal stoves with LPG stoves | 367 | 251,193 |
| 56 | Residential | 30W solar home system | 510 | 349,102 |
| 57 | Transport | BRT Line 1 - CBD to Rususoro (private case) | 547 | 379,854 |
| 58 | Transport | BRT Line 2 - CBD to Gahanga (private case) | 598 | 415,423 |
| 59 | Commercial and public | Building energy efficiency standards | 704 | 481,996 |



# Appendix E. League Table of the Most Carbon-Effective Measures in Kigali (ktCO2-e)

| Rank: | Sector | Measure: | RWF/tCO2-e |
|---|---|---|---|
| 1 | Waste | Centralised anaerobic digestion to electricity | 12,736 |
| 2 | Waste | Landfill gas utilisation | 9,133 |
| 3 | Waste | Landfill gas flaring (65%) | 5,512 |
| 4 | Waste | Landfill gas flaring (20%) | 2,513 |
| 5 | Waste | Recycling (40%) | 1,918 |
| 6 | Waste | Home Biogas production | 1,658 |
| 7 | Transport | Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (public case) | 1,340 |
| 8 | Transport | Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (private case) | 1,340 |
| 9 | Transport | Bus network expansion - doubling of 2015 capacity by 2032 (public case) | 1,300 |
| 10 | Transport | Bus network expansion - doubling of 2015 capacity by 2032 (private case) | 1,300 |
| 11 | Waste | Recycling (20%) | 1,056 |
| 12 | Waste | Central composting (30%) | 1,024 |
| 13 | Waste | Home composting (30%) | 1,024 |
| 14 | Transport | Euro IV standards (public case) | 865 |
| 15 | Transport | Euro IV standards (government case) | 865 |
| 16 | Waste | Home composting (15%) | 863 |
| 17 | Waste | Central composting (19%) | 657 |
| 18 | Transport | Import age restrictions <10 (public) | 597 |
| 19 | Transport | Import age restrictions <10 (government case) | 597 |
| 20 | Residential | 300L solar water heaters - 50,000 installed by 2032 | 481 |
| 21 | Transport | Electric bike - 5% of trips 2032 (public case) | 355 |
| 22 | Transport | Electric bike - 5% of trips 2032 (private case) | 355 |
| 23 | Residential | 200L solar water heaters - 50,000 installed by 2032 | 321 |
| 24 | Residential | 300L solar water heaters - 30,000 installed by 2032 | 289 |
| 25 | Residential | Replacing incandescent light bulbs with light emitting diodes | 281 |
| 26 | Residential | Replacing incandescent light bulbs with compact fluorescent bulbs | 258 |

Continued

| Rank: | Sector | Measure: | RWF/tCO2-e |
|---|---|---|---|
| 27 | Residential | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs | 258 |
| 28 | Transport | BRT Line 2 - CBD to Gahanga (public case) | 256 |
| 29 | Transport | BRT Line 2 - CBD to Gahanga (private case) | 256 |
| 30 | Transport | BRT Line 1 - CBD to Rususoro (public case) | 233 |
| 31 | Transport | BRT Line 1 - CBD to Rususoro (private case) | 233 |
| 32 | Residential | Improved cookstoves (SAVE80 model) | 203 |
| 33 | Transport | Import age restrictions <15 (public case) | 201 |
| 34 | Transport | Import age restrictions <15 (government case) | 201 |
| 35 | Residential | 200L solar water heaters - 30,000 installed by 2032 | 192 |
| 36 | Transport | Parking meters in CBD (public case) | 155 |
| 37 | Transport | Parking meters in CBD (private case) | 155 |
| 38 | Transport | Bike lane investments (public case) | 149 |
| 39 | Transport | Bike lane investments (private case) | 149 |
| 40 | Residential | Replacing compact fluorescent bulbs with light emitting diodes | 148 |
| 41 | Residential | 300L solar water heaters - 10,000 installed by 2032 | 96 |
| 42 | Residential | Improved cookstoves (JICO model) | 90 |
| 43 | Commercial and public | Replacing compact fluorescent tubes with LED tubes - 100,000 tubes | 72 |
| 44 | Residential | 200L solar water heaters - 10,000 installed by 2032 | 64 |
| 45 | Commercial and public | Replacing incandescent light bulbs with light emitting diodes - 100,000 bulbs | 60 |
| 46 | Commercial and public | Building energy efficiency standards | 48 |
| 47 | Commercial and public | 2.5kWp solar panel - 3,000 installed by 2032 | 39 |
| 48 | Commercial and public | Replacing compact fluorescent tubes with LED tubes - 50,000 tubes | 36 |
| 49 | Commercial and public | Street lighting: replacing high pressure sodium bulbs with LED bulbs | 35 |
| 50 | Commercial and public | Replacing incandescent light bulbs with light emitting diodes - 50,000 bulbs | 30 |



Continued

| Rank: | Sector | Measure: | RWF/tCO2-e |
|---|---|---|---|
| 51 | Commercial and public | 300L solar water heater with subsidy – 3,000 installed by 2032 | 29 |
| 52 | Commercial and public | 300L solar water heater – 3,000 installed by 2032 | 29 |
| 53 | Commercial and public | 2.5kWp solar panel – 2,000 installed by 2032 | 26 |
| 54 | Commercial and public | 1.5kWp solar panel – 3,000 installed by 2032 | 24 |
| 55 | Commercial and public | 300L solar water heater with subsidy – 2,000 installed by 2032 | 19 |
| 56 | Commercial and public | 300L solar water heater – 2,000 installed by 2032 | 19 |
| 57 | Residential | 200W solar home system – 15,000 installed by 2032 | 18 |
| 58 | Commercial and public | 1.5kWp solar panel – 2,000 installed by 2032 | 16 |
| 59 | Commercial and public | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs – 100,000 bulbs | 15 |
| 60 | Commercial and public | Replacing incandescent light bulbs with compact fluorescent bulbs – 100,000 bulbs | 15 |
| 61 | Commercial and public | 2.5kWp solar panel – 1,000 installed by 2032 | 13 |
| 62 | Residential | Replacing charcoal stoves with LPG stoves | 13 |
| 63 | Residential | 200W solar home system – 10,000 installed by 2032 | 12 |
| 64 | Residential | 120W solar home system – 15,000 installed by 2032 | 11 |
| 65 | Commercial and public | 300L solar water heater with subsidy – 1,000 installed by 2032 | 10 |
| 66 | Commercial and public | 300L solar water heater – 1,000 installed by 2032 | 10 |
| 67 | Residential | Building energy efficiency – training workshops | 10 |
| 68 | Commercial and public | 1.5kWp solar panel – 1,000 installed by 2032 | 8 |
| 69 | Commercial and public | Replacing incandescent light bulbs with subsidised compact fluorescent bulbs - 50,000 bulbs | 7 |
| 70 | Commercial and public | Replacing incandescent light bulbs with compact fluorescent bulbs – 50,000 bulbs | 7 |
| 71 | Residential | 80W solar home system – 15,000 installed by 2032 | 7 |
| 72 | Residential | 120W solar home system – 10,000 installed by 2032 | 7 |
| 73 | Residential | 200W solar home system – 5,000 installed by 2032 | 6 |

Continued

| Rank: | Sector | Measure: | RWF/tCO2-e |
|---|---|---|---|
| 74 | Residential | 80W solar home system – 10,000 installed by 2032 | 5 |
| 75 | Commercial and public | Replacing compact fluorescent bulbs with light emitting diodes – 100,000 bulbs | 5 |
| 76 | Residential | Replacing kerosene lamps with solar lamps | 4 |
| 77 | Residential | 120W solar home system – 5,000 installed by 2032 | 4 |
| 78 | Residential | 30W solar home system – 15,000 installed by 2032 | 3 |
| 79 | Commercial and public | Replacing compact fluorescent bulbs with light emitting diodes – 50,000 bulbs | 2 |
| 80 | Residential | 80W solar home system – 5,000 installed by 2032 | 2 |
| 81 | Residential | 30W solar home system – 10,000 installed by 2032 | 2 |
| 82 | Residential | 30W solar home system – 5,000 installed by 2032 | 1 |



# The Climate Smart Cities Programme

## www.climatesmartcities.org

The study has been conducted as part of the Climate Smart Cities programme that has been underway since 2009. The programme is led by Prof Andy Gouldson at the University of Leeds with support from the ESRC Centre for Climate Change Economics and Policy.

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.


# Acknowledgements

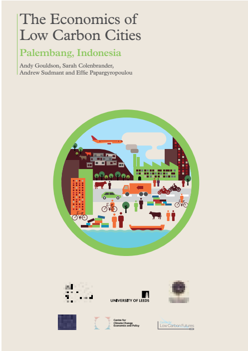
This individual study has been supported by the International Growth Centre. It has been conducted by Andy Gouldson, Sarah Colenbrander, Andrew Sudmant, Natasha Chilundika, Herman Musahara and Lea de Melo.

# Climate Smart Cities

## www.climatesmartcities.org


Kolkata, India


Lima-Callao, Peru




Palembang, Indonesia


Johor Bahru, Malaysia


Recife, Brazil


Leeds City Region


Birmingham and the Wider Urban Area


The Humber


Sheffield City Region


Bristol City Region

**Programme Director:**

**Prof Andy Gouldson**
a.gouldson@leeds.ac.uk

UNIVERSITY OF LEEDS

**Project Manager:**

**Sarah Colenbrander**
s.colenbrander@leeds.ac.uk

UNIVERSITY OF LEEDS

**In-country lead:**

**Herman Musahara**
herman.musahara@gmail.com

OSSREA