The Economics of Low Carbon Cities

Kigali, Rwanda (2018)

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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...

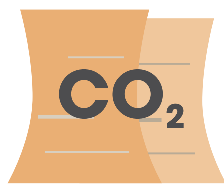
Leads to...

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.

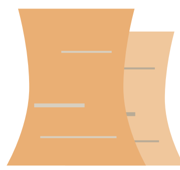
- **Energy**
  reductions in the energy bill of 1.5% of GDP p.a. or savings of $203m in 2032
- **Financial Viability**
  6.9 years for measures to pay for themselves
- **Employment**
  new jobs and skills in low carbon goods and services
- **Wider economic benefits**
  reduced energy expenditure, improved 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

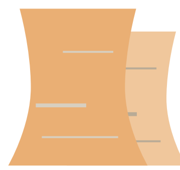


39.0% GHG reduction



Through exploitation of profitable options

42.5% GHG reduction



Through exploitation of no net cost options

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Acronyms	
BRT	Bus Rapid Transit
CO_2-e	Carbon dioxide equivalent emissions. This figure includes all greenhouse gas emissions (including methane and NOx) as CO_2 equivalent emissions.
GWh	Billion watt hours
KtCO_2e	One thousand tonnes of CO_2 equivalent emissions
kWh	Kilowatt hour
LFG	Landfill Gas
MININFRA	Ministry of Infrastructure
MtCO_2e	One million tonnes of CO_2 equivalent emissions
MW	Million watts
REG	Rwanda Energy Group
REMA	Rwandan Environmental Management Authority
RTDA	Rwanda Transport Development Authority
RWF/tCO_2-e	Rwandan Francs per tonne carbon dioxide equivalent
tCO_2-e	Tonnes of carbon dioxide equivalent emissions. This figure includes all greenhousegas emissions (including methane and NOx) as carbon dioxide equivalent emissions.
UNEP	The United Nations Environment Program
USD/tCO_2-e:	United States dollars per tonnes carbon dioxide equivalent

Executive Summary

Introduction

When is economic development, sustainable development? Embedding environmental stewardship in policymaking is critical in all cities and countries of world, but may be especially important in Rwanda, where both the economy and the population are growing rapidly. But for decision-makers to act, they need a credible and locally appropriate evidence base.

This study provides an evidence base for Kigali and examines whether there is an economic case that can be used to secure low-carbon and climate-resilient investments in the city. By providing prioritised lists of the most cost- and carbon-effective measures that could realistically be promoted across the housing, commercial buildings, transport and waste sectors within the city this report serves as a resource for

This report presents results from modelling updated from 2018 data, details of the methodology and a discussion of the opportunities for carbon abatement. In addition to providing a static 'snapshot' of the opportunity for cost- and carbon-effective measures in Kigali today, the models behind the analysis presented can be updated to provide a means for this report to be a 'living document' that can remain useful in the future.

Our Approach

We start the analysis by collecting data on levels and composition of energy use in Kigali. We do this for the electricity, housing, commercial, transport, industry and waste sectors. Primary data was provided by a number of government agencies including the Ministry of Infrastructure (MININFRA), 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 domestic, 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 locally specific 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.

In all parts of this process, analysis is guided by modelling approaches and lessons learned from similar city scale analysis completed by the team over the last 8 years. Including this most recent analysis, the team from the University of Leeds have completed similar analysis in more than 20 global cities, leading to 18 academic publications, and media attention ranging from the New Climate Economy, the New York Times and the Economist.

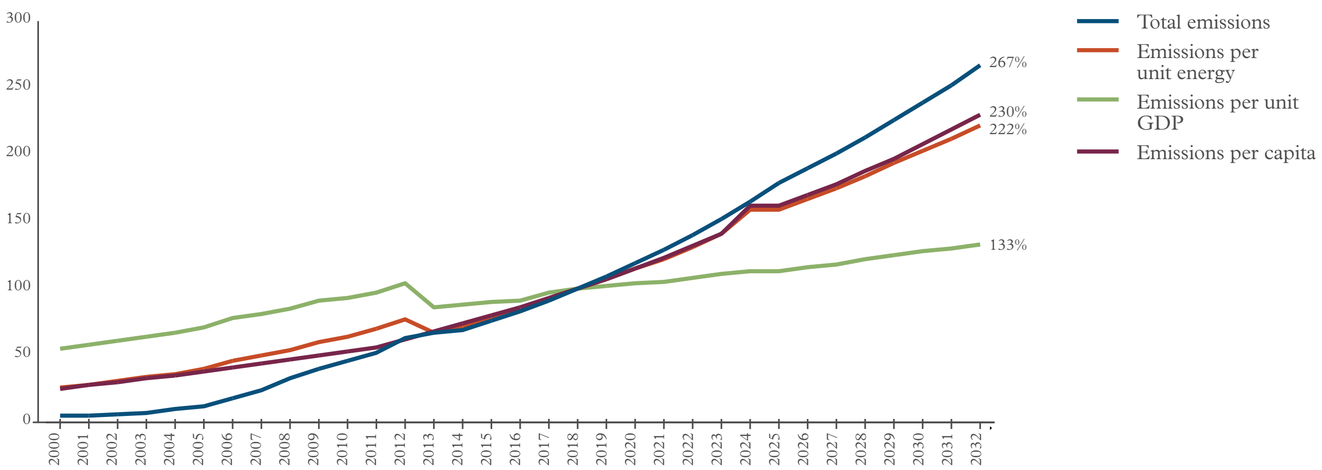
Findings and Recommendations

The Economic Case for Low-Carbon, Climate-Resilient Investment

We estimate that Kigali's GDP was RWF 2.1 trillion (USD 2.4 billion) in 2018, and if trends continue we forecast that GDP will grow to RWF 9.5 trillion (USD 11.9 billion) by 2032. We also find that the total energy bill for Kigali in 2018 was RWF 220.1 billion (USD 252.9 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 will see the total energy ill for the city increase by 167% from 2018 levels to RWF 720.8 billion (USD 828 million) in 2032**, a trend shown in figure 1. Total energy use in Kigali will rise by 130% in the same period. With continued economic growth, this would mean that energy bills will consume an estimated 7.7% of the GDP of Kigali in 2032. We also predict that, in a business as usual scenario, total carbon emissions from Kigali will increase by 122% from 2018 levels by 2032, while emissions per capita will increase 33%.

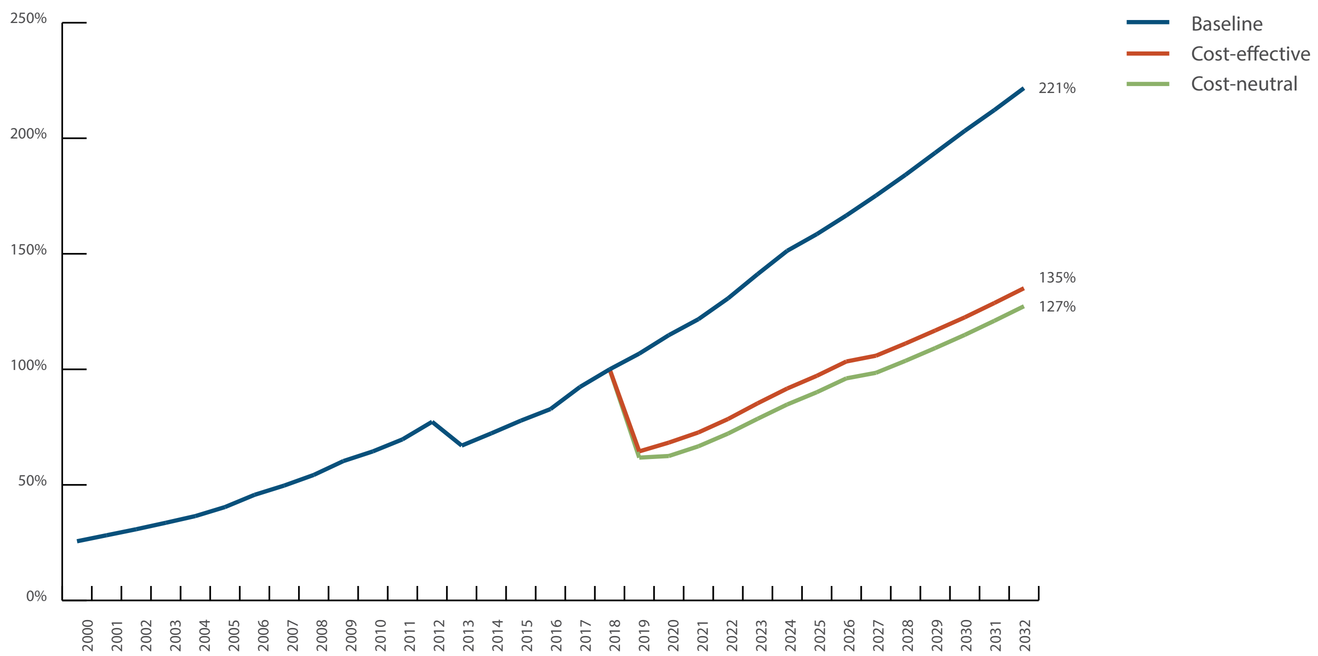
Figure 1: Indexed energy bill, energy use, and carbon emissions.



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 780 billion (USD 918 million), **generating annual savings of RWF 115 billion (USD 132 million)**, paying back the investment in 6.9 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 1.2 trillion (USD 1.4 billion), **generating annual savings of RWF 152 billion (USD 174 million)**, paying back the investment in 8 years and generating annual savings for the lifetime of the measures

Figure 2: Emissions from Kigali under three different investment scenarios, indexed against 2018 emissions, between 2000 and 2032.



We find that the waste sector contains approximately 60% of the cost-effective emissions savings potential in Kigali, with the remaining potential being distributed among the domestic sector (3%), the commercial and public sector (2%), the electricity sector (19%) and the transport sector (17%). 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 is so significant for two reasons. Firstly, as in many other Least Developed Country cities, waste is a much larger share of emissions than in higher income contexts. 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. It is important to note, however, that emissions are growing much more quickly in each of the other sectors of the economy investigated in this analysis. Actions in these sectors is therefore critical to avoid a future of high emissions, and expenditure on energy, in Kigali.

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). **With exploitation of all cost-effective options, by 2032 emissions would be 35% above 2018 levels.** These measures will also save RWF 118.6 billion (USD 173.2 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 27% above 2018 levels.

Investment in emissions savings can buy Kigali 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, in this case 2025 (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. This can give policymakers time to build the political momentum and the technical, financial and institutional capabilities necessary for more ambitious changes to urban form and function.

Policy reflections

Development and climate action can be mutually supportive. Indeed, results from this analysis suggest that achieving the goals set in Rwanda's Vision 2020, Economic Development and Poverty Reduction Strategy II (EDPRS) and the targets of the Sustainable Development Goals, can be significantly supported by actions that also address climate change.

High-level results from this analysis reveal that **there are many economically attractive opportunities to promote a more sustainable and climate-friendly f orm of development in Kigali**, which would also improve the economic competitiveness of and reduce energy bills in the city. 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.

Results at the economic sector level demonstrate that the case for action is not restricted to any one area of the economy or concentrated in a small number of actions. Instead, the opportunity for action is contained in a large number of actions in all sectors. Some of these actions could have a major effect on emissions, for example, land-fill gas utilisation at Kigali's landfills. Others of these actions, such as electric motorbikes and clean cookstoves only have a small effect on energy use and emissions each time they are purchased. But if policies could promote their widespread adoption these actions have massive potential to help address climate and development challenges, and lead Kigali towards a low carbon future.

Future emissions growth will increasingly come from the transport, residential, commercial and industrial sector making the major sources of emissions in Kigali 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.

At the same time, **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 motorbikes), investments in geothermal electricity generation and spatial planning.**

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 exploited. By providing evidence on the scale and composition of these opportunities, we hope that this report will help to build political commitment and institutional capacities for change. We also hope this report will help Kigali to secure the investments and develop the delivery models needed for ambitious climate action. Some of the low-carbon and climate resilience measures could be commercially attractive whilst others may only be viable with public investment and/or climate finance. Many of the opportunities would benefit from the support of enabling policies from government.

We stress that economic cost 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 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, activities in cities consume 67-76% of all energy and are responsible for 71-76% of all carbon emissions (UNEP, 2012). Some estimates suggest that 10-18% of all income that is earned in cities is spent on energy (Gouldson et al., 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, water and development could be changed in a rapidly growing city with pressing development needs. The report reviews the cost- and carbon-effectiveness of a wide range of supply and demand measures options that could be applied to energy and water 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, more climate-resilient 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. 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 set an aim for 35% of the population to have access to electricity and 60% to have access to improved sanitation facilities by 2020. These targets were revised in 2012 to 70% and 100% respectively. In both versions of Vision 2020, a target of 100% access to clean water was established (MINECOFIN, 2012).

While Rwanda's economic growth is rapid, future development and poverty alleviation remains vulnerable to climate variability and climate change. Rwanda's population is largely rural and depends on rain-fed agriculture; tea and coffee comprise a large proportion of Rwanda's export earnings; and hydropower generates half of domestic electricity (Republic of Rwanda, 2011; AfDB, 2013).

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 (REMA) 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 0.1 tonnes of carbon dioxide equivalent (tCO_2-e) per person from energy consumption and 0.6tCO_2-e per person when emissions from land use change are incorporated (Republic of Rwanda, 2011). For reference, the global average is 4.6tCO_2-e from energy consumption (EIA, 2012), while people in OECD countries emit an average of 12.7tCO_2-e per capita (OECD, 2015).

Kigali

Rwanda remains predominately rural, with 19.9% of the population living in urban areas (NISR 2012). With a population of 1.5 million people (Bower, Buckley, Murray & Wainer, forthcoming), the capital city – Kigali – accommodates 13% of the population and is easily the largest city in Rwanda (NISR, 2012). 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, 2012), 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, and 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 (SEI, 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 if 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 in the central business district, 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, climate-resilient development strategy.

Objectives

What is the best way for a city to pursue low-carbon, climate-resilient 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 and climate-resilient 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 supplemented by an economic assessment of supply and demand measures in the water sector. Water and sanitation are among the basic infrastructure services that are fundamental to human development, and the foundation on which human settlements are built and function (Satterthwaite, 2014). Failure to provide these services increases people's vulnerability to climate variability and natural disasters: for example, the urban poor have to buy water from vendors at greatly inflated prices during the dry season and experience higher risk of waterborne disease during floods. Investing in infrastructure to ensure access to cheap, reliable and safe water therefore supports climate resilience and human development.

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 measures, we aim to help government departments, development agencies, industry and civil society organisations to design climate strategies that exploit the most economically attractive measures. This evidence base has the potential to underpin national applications to international climate funds, development banks and other financial organisations, thereby helping to unlock and direct large-scale investment into low-carbon development.

Chapter 2. Our Approach

Baseline Analysis

We start by collecting data that enable us to understand the levels and composition of energy and water 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.

Data from the Rwanda Environment Management Authority and Bloomberg New Energy Finance were used to calculate historical generation, capacity factors and generation efficiency. The baseline scenario was developed based on planned capacity expansions, investment costs and anticipated technical losses through 2017/18, drawn from the Ministry of Infrastructure, Japan International Cooperation Agency, and the Rwanda Environment Authority.

Planned infrastructure investments in Kigali are drawn from the Kigali City Master Plan and Rwandan Transport Development Authority. Transport mode share in Kigali in 2011 was drawn from a revealed preference dataset, while the number of trips per day, average vehicle speed, occupancy rates, travel time and walking distances by travel mode were drawn from a hierarchical multimodal transport model. The number of trips by private transport is assumed to grow in proportion to vehicle ownership, and the number of trips by bus is assumed to increase with the expected number of buses (in other words, we assume occupancy for vehicles is held constant). The proportion of trips made on foot and by heavy transport was held constant, and trips by motos was considered the residual.

Data on electricity consumption in Kigali by private customers (excluding industry) and public sector customers were obtained in personal communications from the Rwanda Energy Group. Annual per capita consumption of kerosene, charcoal and fuelwood were held constant at 52L, 194kg and 366kg respectively, while the number of households using these fuels were obtained from the Integrated Households Living Conditions Survey in 2006, 2011 and 2015. Commercial and public consumption of fuelwood and charcoal in Kigali was projected to increase at a constant rate, based on levels of consumption in 2009 and 2020. All liquefied petroleum gas (LPG) consumed in Rwanda between 2003 and 2007 was assumed to have been consumed in Kigali, and city-scale data were subsequently available for 2009 and 2020. Historical growth rates between 2010 and 2015 were projected to continue through to 2032 at the same rate.

The composition of waste was assumed to remain constant through 2032: food waste (67%), paper waste (16%), garden waste (7%), industrial waste (4%), wood waste (3%), textiles (2%) and plastics/metal (1%). Per capita waste production is expected to rise from 1.8 kg per day in 2011 to 2.0 kg per day in 2030. Waste disposal methods were drawn from the population and housing censuses of 2002 and 2012. The cost of waste disposal was drawn from the Kigali City Master Plan, and the characteristics of landfills serving Kigali from academic sources.

Data on energy use by industry is not available at the city scale in Rwanda.

Data on electricity prices were obtained from the Statistical Yearbooks published in 2013, 2014 and 2015 and data from the Management of Energy Utility Corporation Limited for 2017 (EUCL). Data on the price of charcoal and fuelwood were obtained from the Global Environmental Facility, the Biomass Energy Strategy, the Rwanda Natural Resources Authority and academic sources. Data on the prices of kerosene, LPG and gasoline were obtained from the Biomass Energy Strategy, the World Bank, United Nations agencies and regional newspapers such as The New Times and The Independent. Nominal energy prices were converted into real energy prices at 2014 levels using a consumer price index. An annual increase of 2% in real terms was assumed for all energy prices from 2018 to 2032.

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 such a short time 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 estimate 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.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.

Key baseline data and assumptions

Activity	Projection method	Key data
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). 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: RWF 158.0/kWh (residential) RWF 149.0/kWh (industrial) Diesel: RWF 919/L Gasoline: RWF 989/L Charcoal: RWF 166.9/kg Fuelwood: RWF 81.3/kg (residential) Kerosene: 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). The current exchange rate was obtained from www.xe.com at 12 noon GMT 23/05/18.	USD 1.00 = RWF 870

Activity	Projection method	Key data in 2014
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 2017/18a are drawn from MININFRA (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 MININFRA (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 2018: 0.39 tCO_2e/MWh Rwandan electricity grid emissions factor 2032 estimate (excluding losses): 0.41 tCO_2e/MWh
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. 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). 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). Commercial and public consumption of fuelwood and charcoal in Kigali in 2009 and 2020 was obtained from Drigo et al. (2013). Using the GROWTH function in Excel, 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.	

Activity	Projection method	Key data in 2014
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.	.3
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: Walking: 9% Private vehicles: 24% Heavy vehicles: 4% Mini-bus: 28% Moto-taxi: 16% Bus: 18% Business-as-usual mode share (2032): Walking: 9% Private Vehicles: 36% Heavy Vehicles: 4% Mini-bus: 16% Moto-taxi: 25% Bus: 10%

Activity	Projection method	Key data in 2014
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. Waste composition: Food: 67% Garden: 7% Paper: 6% Wood: 3% Textiles: 2% Industrial: 4% 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%.	

Identification and Assessment of Measures

Lists of 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 were collected through stakeholder consultation, review of grey and academic literature, and previous Climate Smart City studies.

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.

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

Electricity sector

Through an iterative participatory process, involving members of the Rwandan Ministry of Infrastructure, Bloomberg New Energy Finance, and energy developers in Rwanda, 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.

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

Table 1: Energy generation by scenario (MW)

Technology	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

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

Table 2: Key technology-specific values (2015-2032 averages)

Technology	Capacity factor	Capital cost (USD million/MW)	Operating and maintenance costs (cents per KWh)
Hydro	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
Natural gas	0.85	3.00	0.50
Diesel	0.61	3.00	27.00
Imports	–	case specific	7.50

Sources:
NEF (2015), AFDB (2013), MININFRA (2011), REMA (2014), JICA (2015) and stakeholder onsultation.

Commercial and public sector

Measure	Costs	Savings
Building energy efficiency – training workshops	The incremental costs of improving new commercial and public buildings in a moderate efficiency scenario cost USD 886/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)".	The economic savings are based on avoided investment in, and energy consumption by, air conditioners. We assume the cost of a 5kW air conditioner is RWF707,143, i.e. proportionate to those of a 3.5kW air conditioner. The total number of air conditioners by 2032 is based on cooling needs of 5W/m2. This is low level of cooling reflects Kigali's temperate climate. Total amount of retail, office and hotel floor space is based on projections from the City of Kigali's Master Plan.
More efficient lighting	Incandescent bulbs cost RWF 630.62. Compact fluorescent lamps (CFL) cost RWF 2,541. CFL tubes cost RWF 4,109. Light emitting diodes (LED) cost RWF 22,671. LED tubes cost RWF 44,521. The price of a subsidised CFL bulb is RWF 200. We assumed that CFL bulbs and tubes would entirely replace incandescent options by 2030 without policy interventions. We assume 0% LED market penetration in Kigali in 2015.	Incandescent bulbs have an average input power of 60W and a life span of 1,200 hours. Compact fluorescent lamps (CFL) have an average input power of 14W and a life span of 10,000 hours. CFL tubes have an average input power of 25W and a life span of 8,000 hours. Light emitting diodes (LED) have an average input power of 10W and a life span of 50,000 hours. LED tubes have an average input power of 8W and a life span of 40,000 hours.
Solar panels	A 250Wp solar panel cost RWF 276,000, so we assumed a 2.5kWp solar panel cost ten times as much. We assumed 3,000 could be deployed by 2032.	Solar panels are assumed to have a conversion efficiency of 14.5% and life span of 20 years.
Solar water heaters	A 300L solar water heater has an average cost of US$1,600. The subsidy for a 300L solar water heater is RWF 279,000, less an application fee of RWF 30,000. We assumed 3,000 could be deployed by 2032, in light of scope for substantial uptake in the hospitality industry.	Installing 12,000 solar water heaters would save 23,328MWh per year. We assumed this was based on equal deployment of 200L and 300L solar water heaters, i.e. a 300L solar water heater would save 2,332.8kWh per year. We assumed a lifespan of 15 years.
Street lighting	There are three levels of power required in Rwandan street lights: – 15 poles with low wattage: 150W bulbs will be replaced with 80W LED bulbs – 6251 poles with medium wattage: 250W bulbs will be replaced with 120W LED bulbs – 800 poles with high wattage: 400W bulbs will be replaced with 200W LED bulbs Fixtures and lamps for high pressure sodium bulbs cost USD 250, with an annualised replacement cost of USD 14.4. Fixtures and lamps for LED bulbs cost USD 475, with an annualised replacement cost of USD 7.2.	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.

Residential sector

Measure	Costs	Savings
Building energy efficiency – training workshops	Kigali City Council currently holds training workshops at RWF 11 million per workshop. We assume no additional costs associated with constructing green residential buildings as passive cooling levels can be achieved by, for example, optimising building orientation or window-to-wall ratios.	Economic savings are based on avoided investment in, and energy consumption by, air conditioners. A 3.5kW air conditioner cost RWF 495,000. We assume 2 hours of use per day 100 days per year, and savings enjoyed by 1% of households in Kigali.
Improved cookstoves	An improved SAVE80 cookstove costs US$100 and has a lifespan of 10 years.	The quantity of woody biomass saved per year is 0.495 tonnes. 88.6% of the woody biomass saved is from non-renewable sources.
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. The price of a subsidised CFL bulb is RWF 200.	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. We assumed that CFL bulbs have not achieved market penetration independent of World Bank support, but would be entirely replaced with CFL bulbs by 2030 without policy interventions. We assume 0% LED light bulbs in Kigali in 2015.
Solar home systems	A 200Wp solar home system requires a down payment of US$86 and monthly payments of US$47 for three years.	We assume a conversion efficiency of 17%, life span of 20 years and deployment of 15,000 units by 2032.
Solar lamps	The kerosene lamps cost US$1. Solar lamps cost US$30 and have a lifespan of 5 years.	Solar lamps replace kerosene lamps, which would consume approximately 1L per week.
Solar water heaters	A 200L solar water heater has an average cost of US$1,300, although it enjoys a subsidy of RWF 186,000 (less an application fee of RWF 30,000).	A 200L solar water heater would save 1,555.2kWh per year. We assume a lifespan of 15 years and deployment of 50,000 units by 2032.

Transport sector

Measure	Costs	Savings
Bike lanes (40km)	Capital costs and maintenance costs are estimated using the Bogota Cicloruta as a case study and the 'Share the Road' cycling project in Nairobi.	Impacts on transport modal share are informed by regional studies and case studies of Bogota and Cape Town.
Parking meters in CBD	350 meters are installed and operate 12 hours per day. Cost for installation and maintenance are informed by academic literature.	The occupied rate (50%) and cost per hour (RWF 100) were determined by consultation.
Import restrictions on private vehicles: **<15 years old** **<10 years old** **Euro IV performance standards**	Data on vehicle imports, prices, import taxes, vehicle efficiencies and the elasticity of demand for vehicles were drawn from previous work completed by the Rwandan Transport Development Agency.	The economic case compares lost tax revenue from vehicles not imported against additional revenue from purchases of younger vehicles. We assume 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.
Bus Rapid Transit (BRT) lines: **CBD to Rusororo** **CBD to Gahanga.**	Construction costs are drawn from the Rwandan Transport Development Authority. c	Operating days, operating hours and tariffs are drawn from the Ministry of Infrastructure and the Rwandan Transport Development Authority. The fuel efficiency of vehicles is assumed to be 2.5 km/l. Fuel costs are assumed to be 35% of total operating costs.
Electric motorbikes	Electric bike costs were provided by a private company, Ampersand, at $1176 each including the cost of a replacement battery and local taxes.	Bike efficiencies, annual kilometres and lifetimes were provided by a private company, Ampersand. We assume that electric motorbikes reach 5% of total passenger trips by 2032 by taking modal share from moto transport. Individuals can finance their electric bike at an annual interest rate of 34.5% over two years.
Doubling bus network capacity: **Standard buses** **Euro IV buses**	Capital cost, operating costs, fuel efficiencies, operating days, operating hours, vehicle lifespans and travel tariffs are drawn from the Kigali Masterplan and the Ministry of Infrastructure. We assume that Euro IV buses cost 40% more than conventional buses based on consultation with transport providers in Kigali.	We assume that bus occupancy remains constant through 2032, and that Euro IV buses operate at 20% higher efficiency than the existing vehicle stock based on consultation with transport providers in Kigali.

Waste sector

Measure	Costs	Savings
Landfill gas flaring and utilisation	Capital costs, operational costs and flaring efficiencies are based on data from the World Energy Council, the International Renewable Energy Agency, and Clean Development Mechanism projects in South Africa and Ghana	We assumed 75% landfill gas collection efficiency and a 10% oxidation factor due to landfill cover. Emission reductions are estimated using data from the Environmental Protection Agency and European Communities. For landfill gas utilisation, we assume that 10% of the electricity generated is used on site and revenue from the remainder is sold at 10 US cents/Kwh.
Composting: **Centralised (windrow)** **Home (recycled receptacles)**	Capital and operational costs are based on CDM composting projects in Uganda and comparative studies on composting. We assumed a participation rate of 30%, based on targets established by the City of Kigali.	Emissions savings are calculated using data from the IPCC and European Communities. The centralised composition option assumes revenue from the sale of compost, with current prices obtained from local stakeholders involved in composting.
Energy-from-waste using anaerobic digestion	Capital and operational costs for a 15MW plant are based on case studies in Europe. Emissions resulting from the construction of the plant are derived from academic literature.	It is based on an electricity-only recovery scenario. Calculations of electricity generation potentials and avoided carbon emissions from energy displaced are calculated using data from the IPCC and European Communities.
Recycling	Capital and operation costs are based on European case studies. We assume that waste is separated at source, but goes through additional sorting at the recycling facility.	The yield of recycling material is based on consultations with local stakeholders. The revenue from the sale of paper is assumed to be 36 USD/tonne while sale of plastic is assume to be 150 USD/tonne. Additional emissions from extra transportation of recycled materials are accounted for.
Biogas production	Biodigester construction costs are derived from case studies in Rwanda and India. A conservative yield of 10% of commercial food waste is targeted.	Gas produced is assumed to be used in-house by restaurants, hospitals, prisons and schools, so savings are derived from avoided purchase costs. Emissions savings are calculated using data from the IPCC and European Communities.

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 nto 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 mitigation potential

We draw together our estimates of the performance and scope for deployment of each measure to determine the aggregate impact on the city. This allowed us to estimate overall investment needs and payback periods, as well as impacts on energy expenditure and greenhouse gas emissions. The resulting economic case is presented from the perspective of the city as a unit, rather than from the perspective of individual or institutional investors.

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 depend on whether commuters are moving from diesel or hybrid cars, while the mitigation potential of more efficient air conditioners depends on the emission intensity of the grid. The league tables present the impacts of individual low-carbon measures. The city-scale scenarios present the impacts of bundles of low-carbon measures.

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 to 2.1 terrawatt hours (TWh) in 2015 to 6.1 TWh 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 growth in emissions is therefore driven by higher per capita energy consumption and a rising population. The emissions intensity of GDP, on the other hand, will decline slightly as less emission-intensive economic activities develop in the city. Over the period to 2032, per capita emissions are expected to increase by 38% and total emissions by 122%.

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

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, but extensive investment through to 2032 is expected to lead to declining prices. 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 doubling of energy expenditure in the city by 2032.

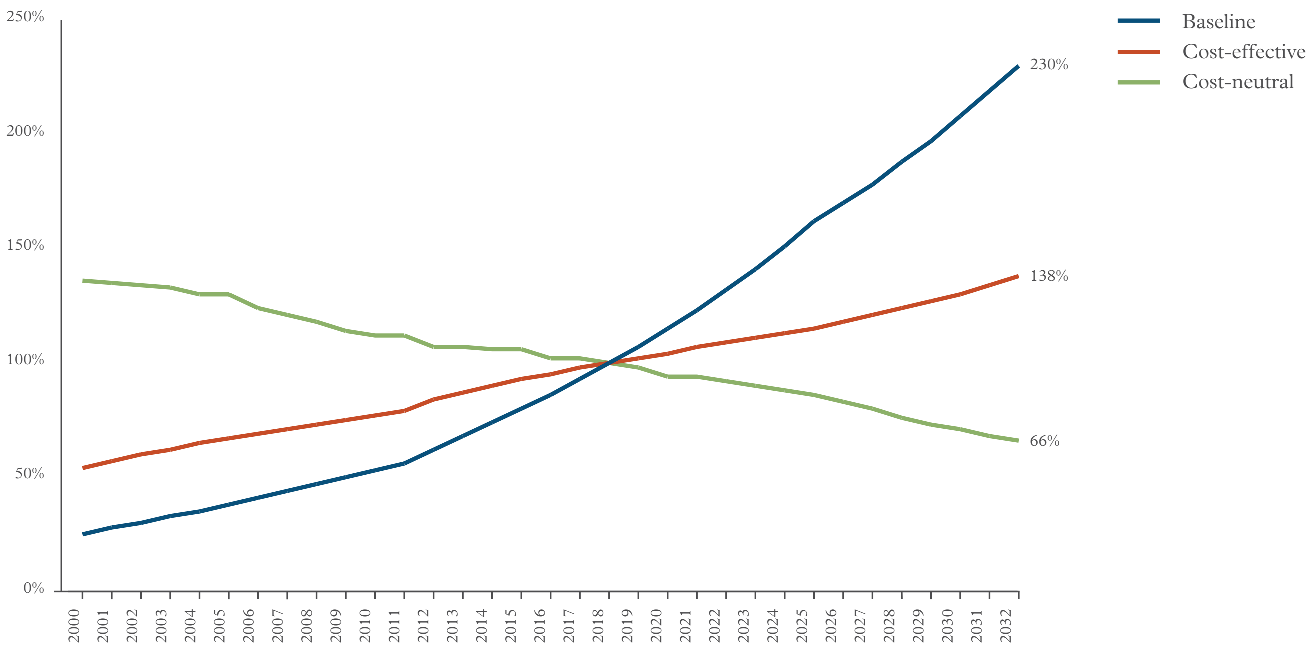
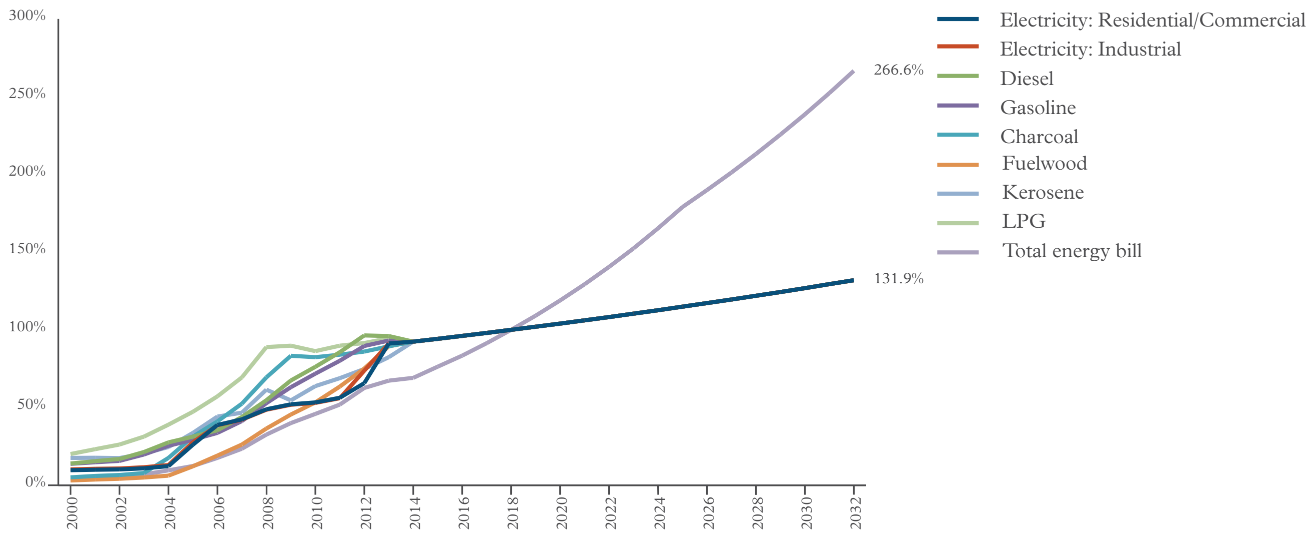


Figure 4: Indexed energy prices and total energy bill.



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.

When combined with relatively stable levels of carbon emissions per unit of energy consumed, total carbon emissions from Kigali increase from 1.2 megatonnes of carbon dioxide equivalent ($MtCO_2$-e) in 2018 to 2.8 $MtCO_2$-e in 2032.

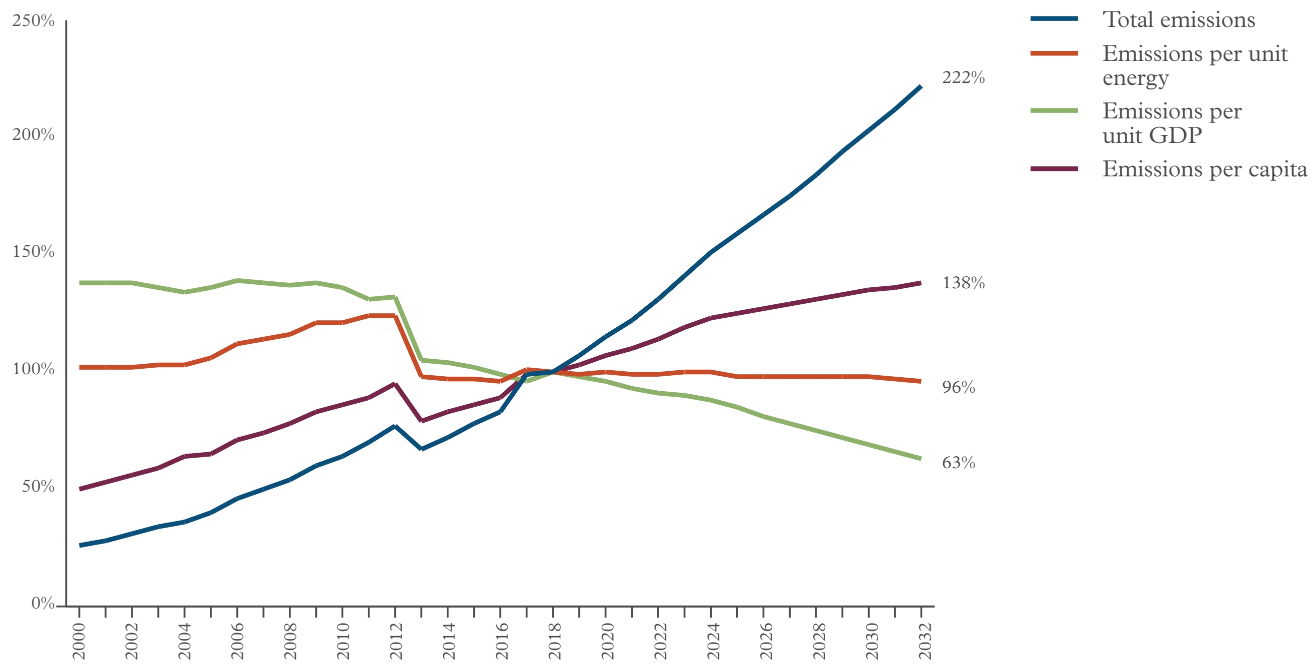
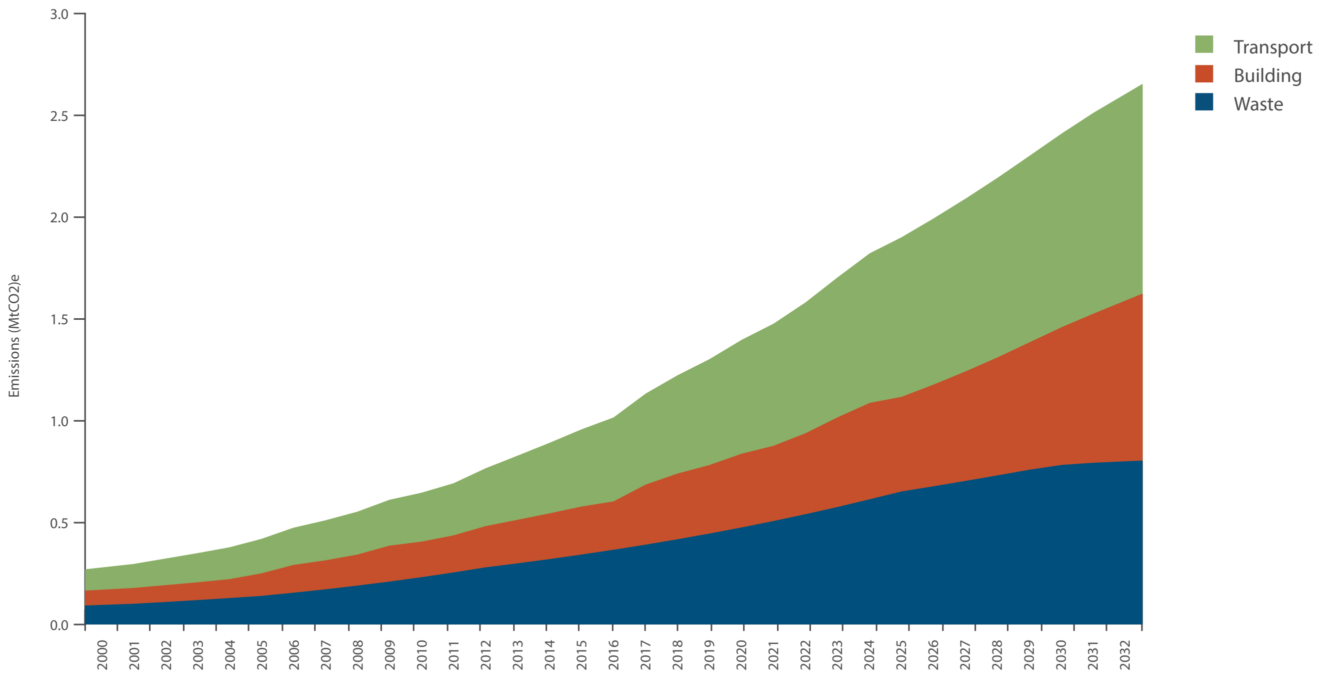


Figure 6: GHG emissions by sector in Kigali, 2000 to 2032



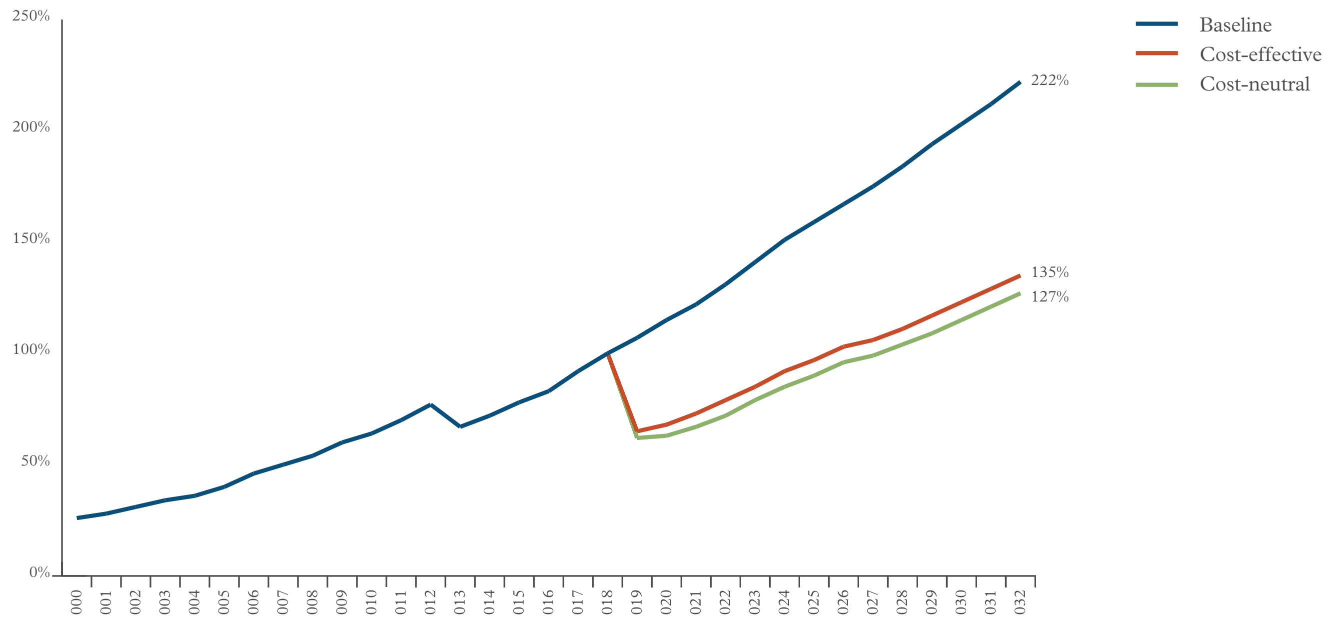
The Potential for Carbon Reduction – Investments and Returns

We find that – compared to 2018 – 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 780 billion (USD 918 million), generating annual savings of RWF 115 billion (USD 132 million), paying back the investment in 6.9 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 1.2 trillion (USD 1.4 billion), generating annual savings of RWF 152 billion (USD 174 million), paying back the investment in 8 years and generating annual savings for the lifetime of the measures

We find that the waste sector contains approximately 60% of the cost-effective emissions savings potential in Kigali, with the remaining potential being distributed among the domestic sector (3%), the commercial and public sector (2%), the electricity sector (19%) and the transport sector (17%). 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 a much larger share of emissions than in higher income contexts. 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.

Figure 7: Emissions from Kigali under three different investment scenarios, indexed against 2018 emissions, between 2000 and 2032.



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 35% above 2018 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 27% above 2018 levels.

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, in this case 2025 (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

In the following, results are present for each of the electricity, buildings, transport and waste sectors. In the league tables provided, results for specific measures are provided. In addition, measures are colour coded. Measures coloured green are included in the cost effective scenario. Measures coloured orange are included in the cost neutral scenario. Measures coloured red are included in the technical potential scenario.

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 expand access and diversify electricity resources over the coming decade. The country's national electrification plan is outlined in the "Economic Development and Poverty Reduction Strategy" 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. 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).

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

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.

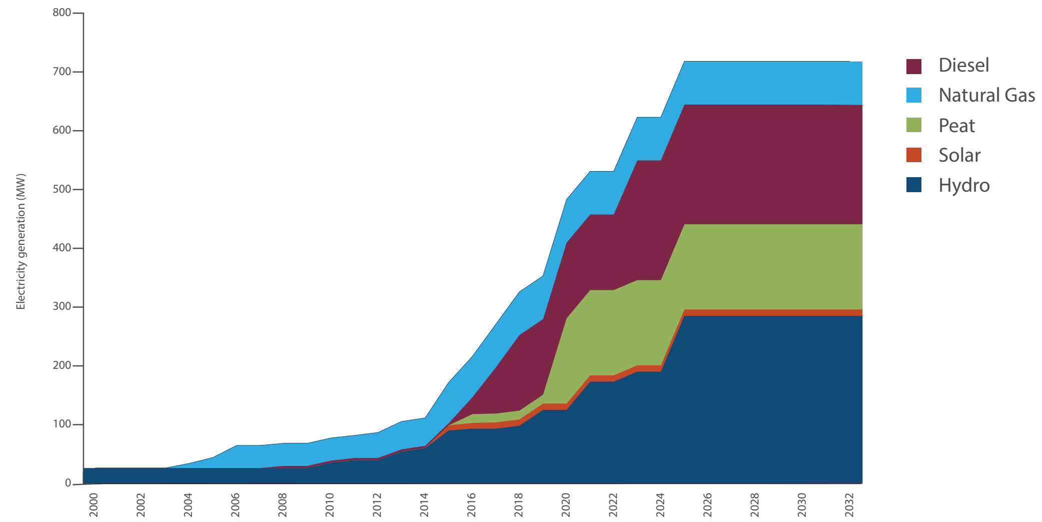
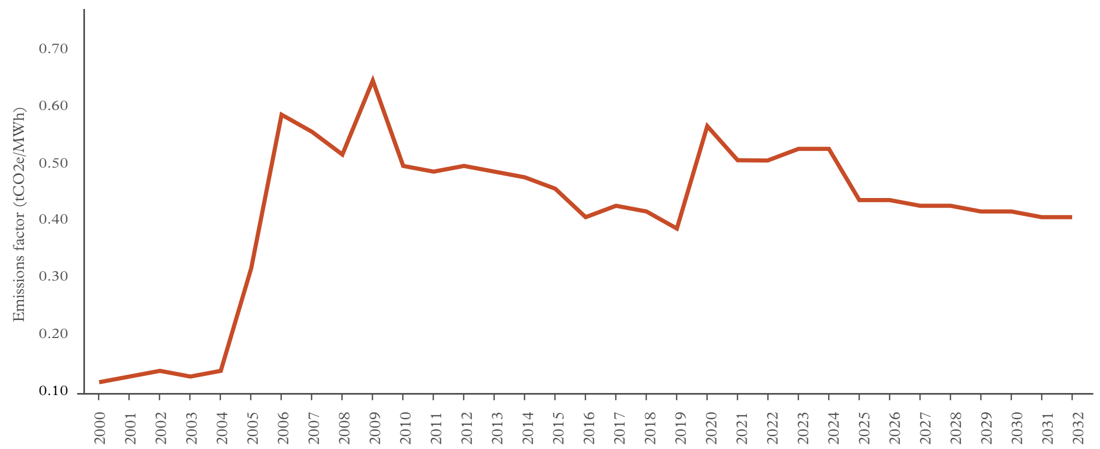


Figure 9: Emissions factor of grid electricity in Rwanda, 2000 to 2032. This emissions factor includes the effects of imported electricity.



The Potential for Carbon Reduction – Investments and Returns

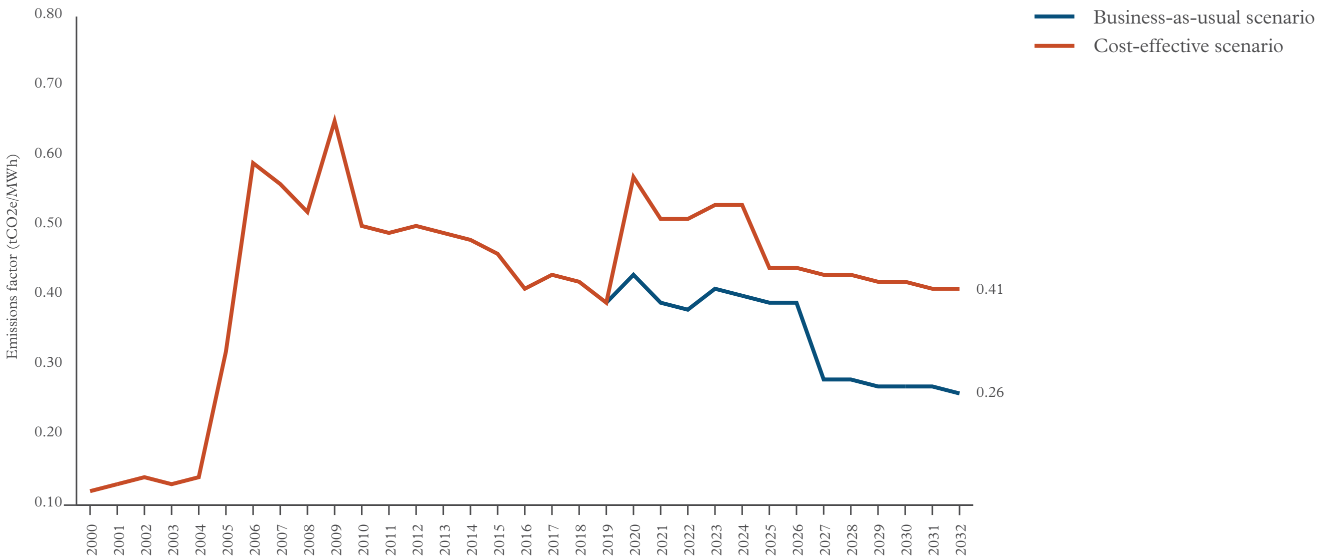
We find that significant reductions in capital expenditure, operating costs and emissions can be achieved through regional grid integration and the gradual exploitation of geothermal resources. This is evident when we compare the levelised cost of electricity in these scenarios to the levelised cost 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 its lifetime.

Under the baseline scenario RWF 2.7 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 139/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 2.3 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 113/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 2.4 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 104/kWh (USD 0.12/kWh).

Figure 10: Emissions factor of electricity in Rwanda between 2000 and 2032 under two 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	-324,510
2	Geothermal 2	-369	-256,294
3	Solar 2	6,943	6,040,410
4	Solar 1	9,244	8,042,280
5	JICA low cost	–	–
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

Kigali needs to construct 8,500-10,000 dwelling units 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 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.

The Impacts of Business as Usual Trends

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 dominant energy source. Energy consumption in this sector is projected to increase 273%, from 782 GWh in 2018 to 2140 GWh in 2032. When combined with increasing real energy prices (particularly rising electricity tariffs), energy expenditure by the buildings sector is projected to be 273% higher, from RWF 55.8 billion in 2018 to RWF 113.7 billion in 2032. Carbon emissions will increase 246%, from 292 ktCO_2-e in 2018 to 795 ktCO_2-e in 2032.

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

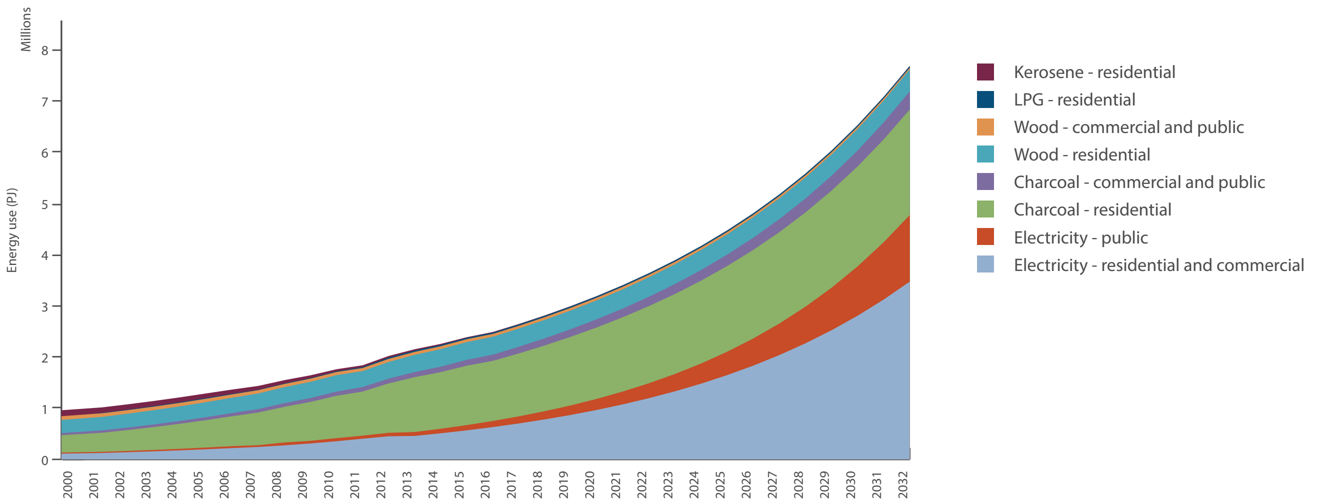
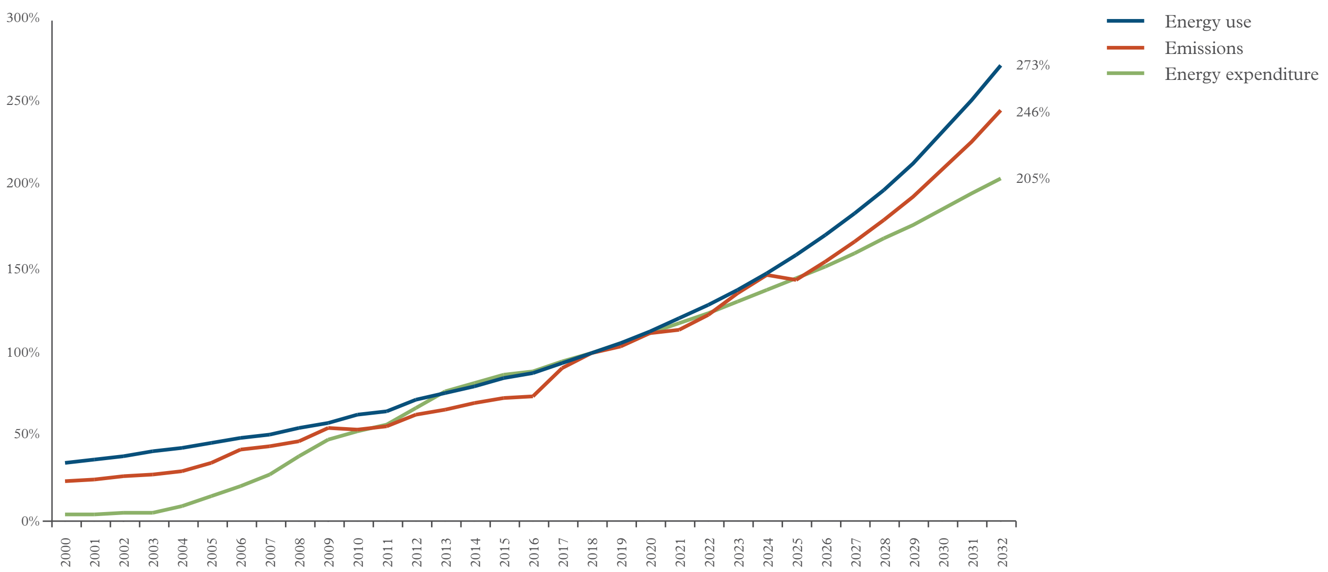


Figure 12: Indexed energy consumption, energy bills and emissions in the buildings sector in Kigali between 2000 and 2032.



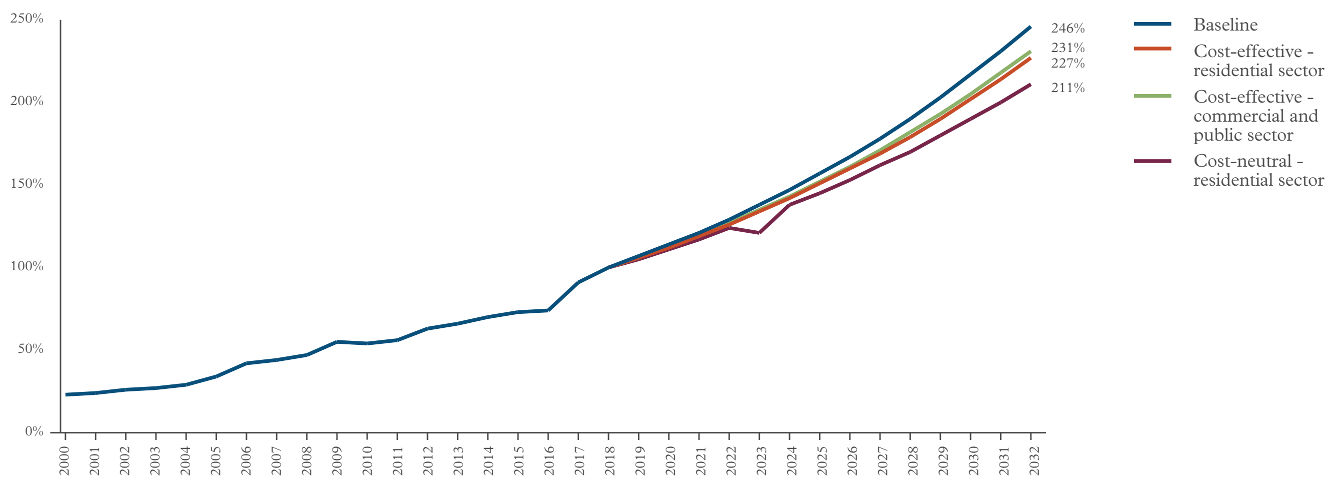
The Potential for Carbon Reduction – Investments and Returns

We find that – compared with 2032 business-as-usual levels – 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 67.8 billion (USD 77.9 million), generating annual savings of RWF 12.0 billion (USD 13.8 million), paying back the investment in 4.5 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 74.6 billion (USD 85.8 million), generating annual savings of RWF 29.7 billion (USD 34.5 million), paying back the investment in 2.5 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 70.6 billion (USD 103.9 million) in the residential sector, generating annual savings of RWF 12.2 billion (USD 14.3 million), paying back the investment in 5.7 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 2018 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	-1,511	-1,314,570
2	Replacing kerosene lamps with solar lamps	-1,421	-1,236,270
3	Replacing incandescent light bulbs with subsidised compact fluorescent bulbs	-349	-303,630
4	Replacing incandescent light bulbs with compact fluorescent bulbs	-332	-288,840
5	Replacing incandescent light bulbs with light emitting diodes	-292	-254,040
6	200L solar water heaters – with subsidy	-233	-202,710
7	200L solar water heaters	-218	-189,660
10	Improved cookstoves (JICO model)	-90	-78,300
11	Improved cookstoves (SAVE80 model)	-71	-61,770
12	Replacing compact fluorescent bulbs with light emitting diodes	-1	-1,027
13	200W solar home system	161	139,635
16	Replacing charcoal stoves with LPG stoves	143	124,027

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

Rank:	Measure:	ktCO2-e
2	200L solar water heaters – 50,000 installed by 2032	321
3	Replacing incandescent light bulbs with light emitting diodes	281
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
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	11
15	200W solar home system – 10,000 installed by 2032	12
17	Building energy efficiency – training workshops	10
20	200W solar home system – 5,000 installed by 2032	6
22	Replacing kerosene lamps with solar lamps	4

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	-349	-303,630
2	Replacing incandescent light bulbs with compact fluorescent bulbs	-332	-288,840
3	Street lighting: replacing high pressure sodium bulbs with LED bulbs	-295	-256,650
4	Replacing incandescent light bulbs with light emitting diodes (LEDs)	-292	-254,040
5	2.5kWp solar panel	-200	-174,000
6	1.5kWp solar panel	-200	-174,000
7	Replacing compact fluorescent tubes with LED tubes	-163	-141,810
8	300L solar water heater with subsidy	-154	-133,980
9	300L solar water heater	-1638	-120,060
10	Replacing compact fluorescent bulbs with light emitting diodes (LEDs)	-1	-870
11	Building energy efficiency standards	499	434,130

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 increases.

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.

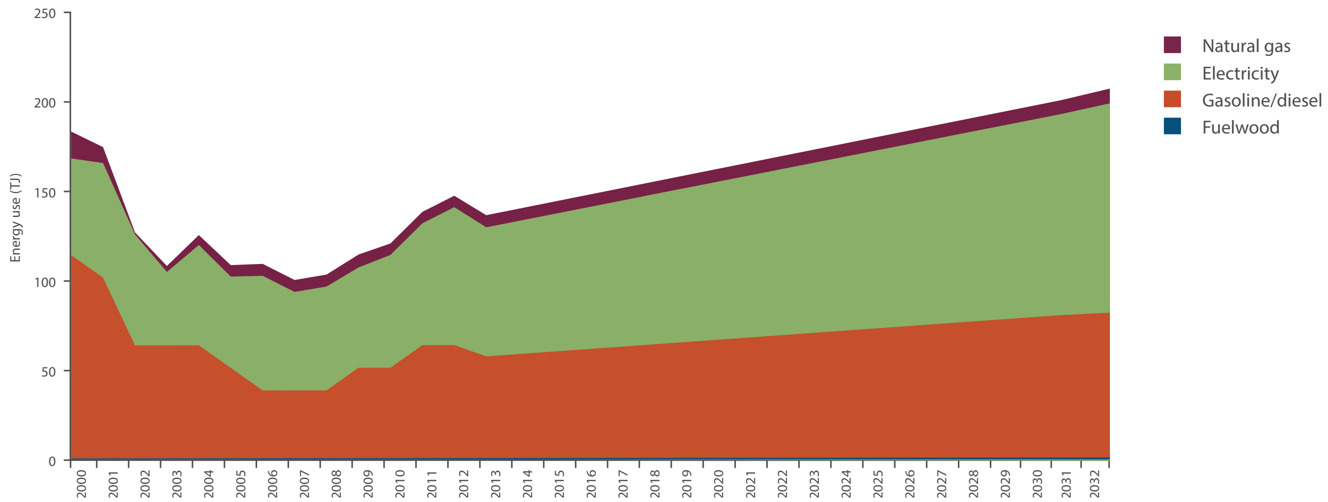


Figure 15: Indexed energy consumption, energy bills and emissions in the manufacturing, construction and non-fuel mining industries in Rwanda between 2000 and 2032.

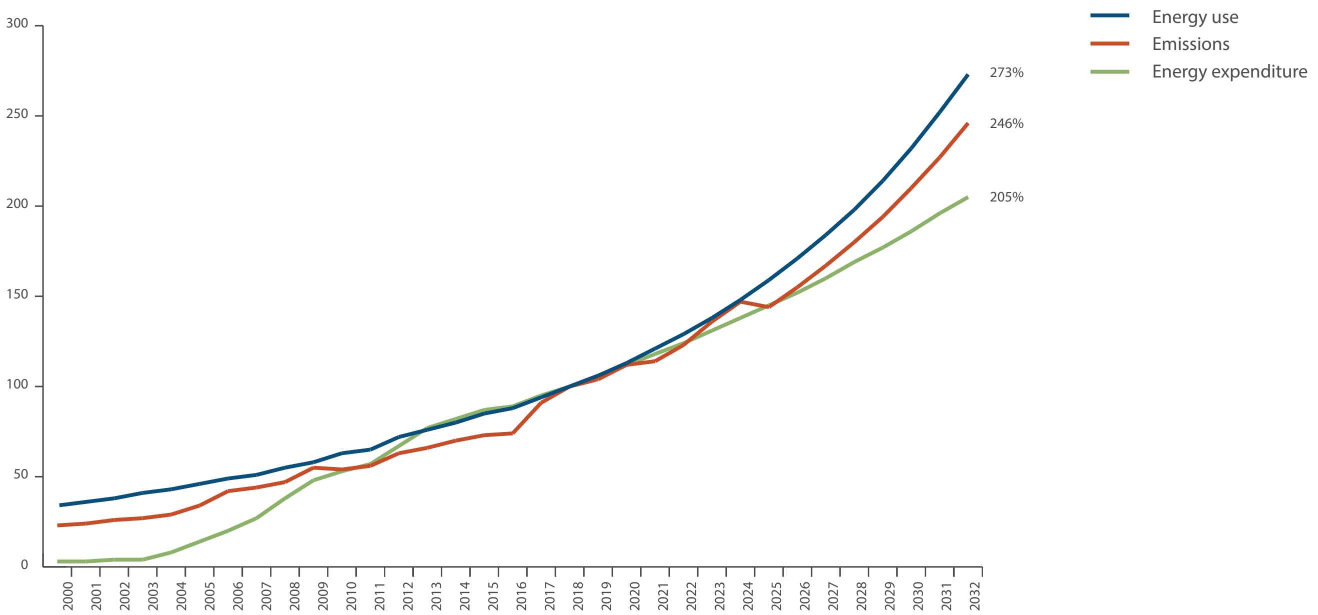
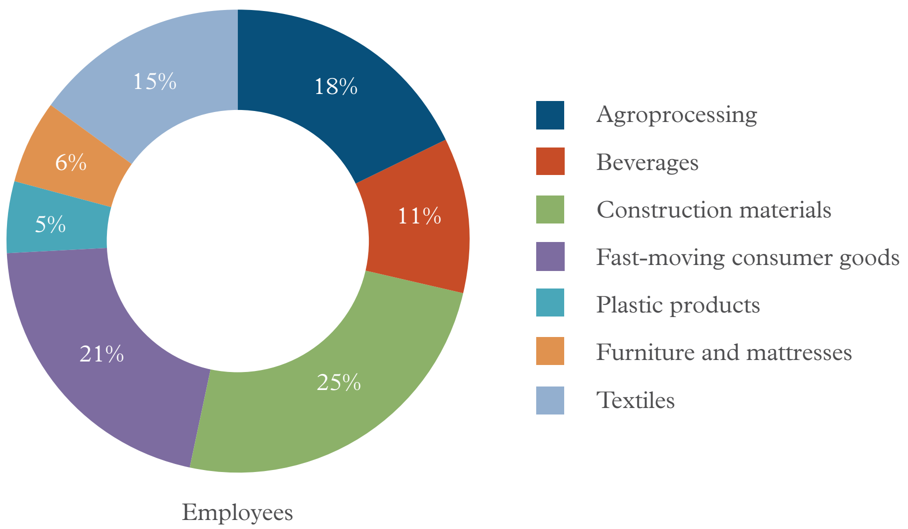


Figure 16: Full-time equivalent employment by industrial sub-sector in Kigali in 2012.



Most industrial activity has historically been and is currently concentrated in Kigali. A few large manufacturing firms have factories in the city, including 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).

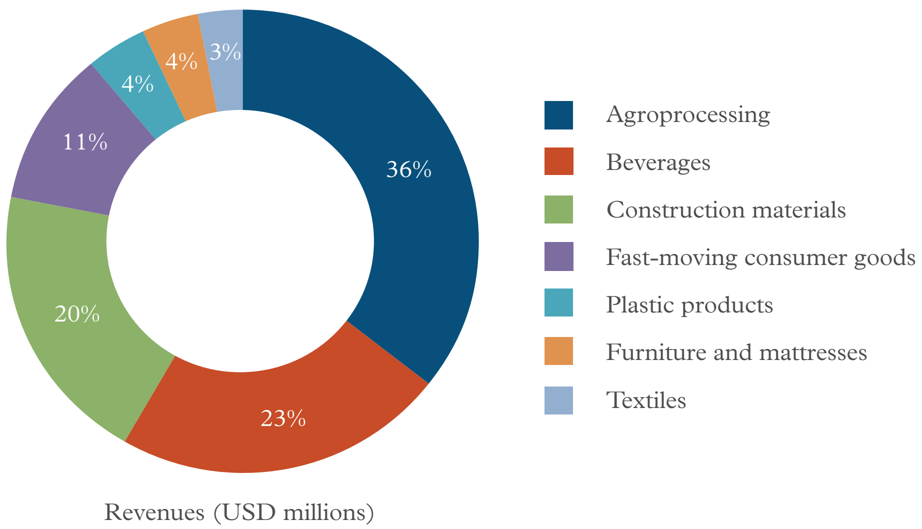
We present below a new overview of employment and revenue by industrial sub-sector in Kigali. Manufacturing of construction materials is the largest employer, following by fast-moving consumer goods and agro-processing. However, the agro-processing industry generates the most annual revenue, followed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

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



Sector Focus

The Transport Sector

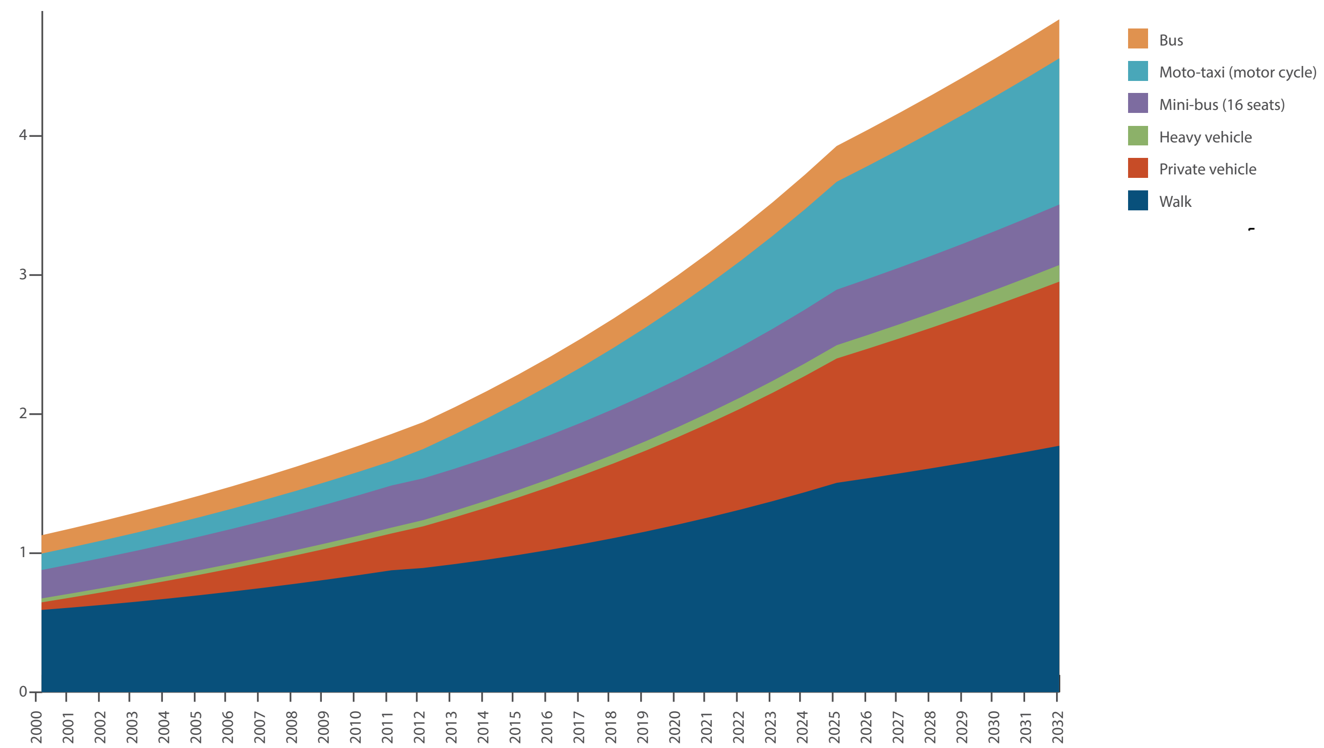
Sector Focus – The Transport Sector

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 grow 212%, from 1.9 TWh in 2018 to 4.0 TWh in 2032. With constant carbon intensity of energy, emissions will increase 210% under business as usual conditions, from 480 ktCO_2e in 2015 to 1023 ktCO_2e in 2032.When combined with increasing real energy prices, energy expenditure in the transport sector is expected to rise 384%, from RWF 158.2 billion (USD 230.0 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 (MININFRA) and the Rwandan Transport Development Authority (RTDA), a semi-autonomous body under MININFRA. Key policies of the transport sector are outlined in the National Transport Policy 2008, the National Transport Sector Investment Strategy 2002, the Integrated National Transport Strategy 2011– 2015 and the Strategic Investment Programme. 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" (MININFRA 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.

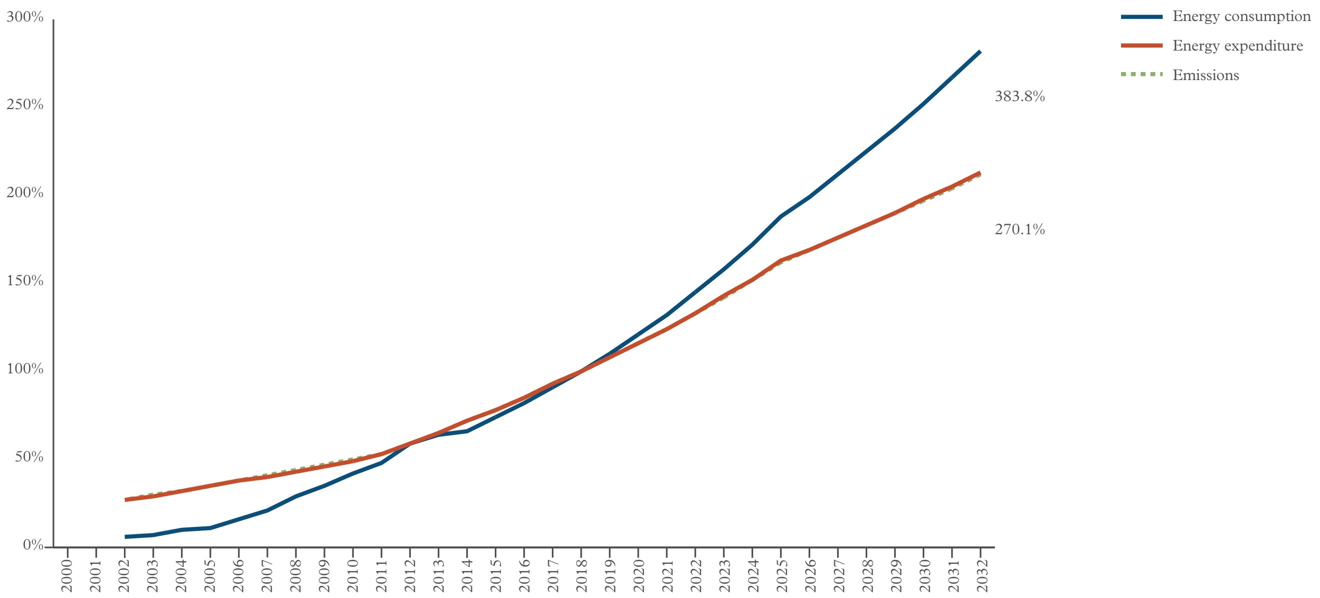


The Potential for Carbon Reduction – Investments and Returns

We find that – compared to 2032 business-as-usual levels – 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 415.7 billion (USD 477.8 million), generating annual savings of RWF 39.4 billion (USD 45.3 million), paying back the investment in 10.5 years and generating annual savings for the lifetime of the measures.– 17.6% 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 709.5 billion (USD 815.5 million), generating annual savings of RWF 56 billion (USD 64.5 million), paying back the investment in 11 years and generating annual savings for the lifetime of the measures.

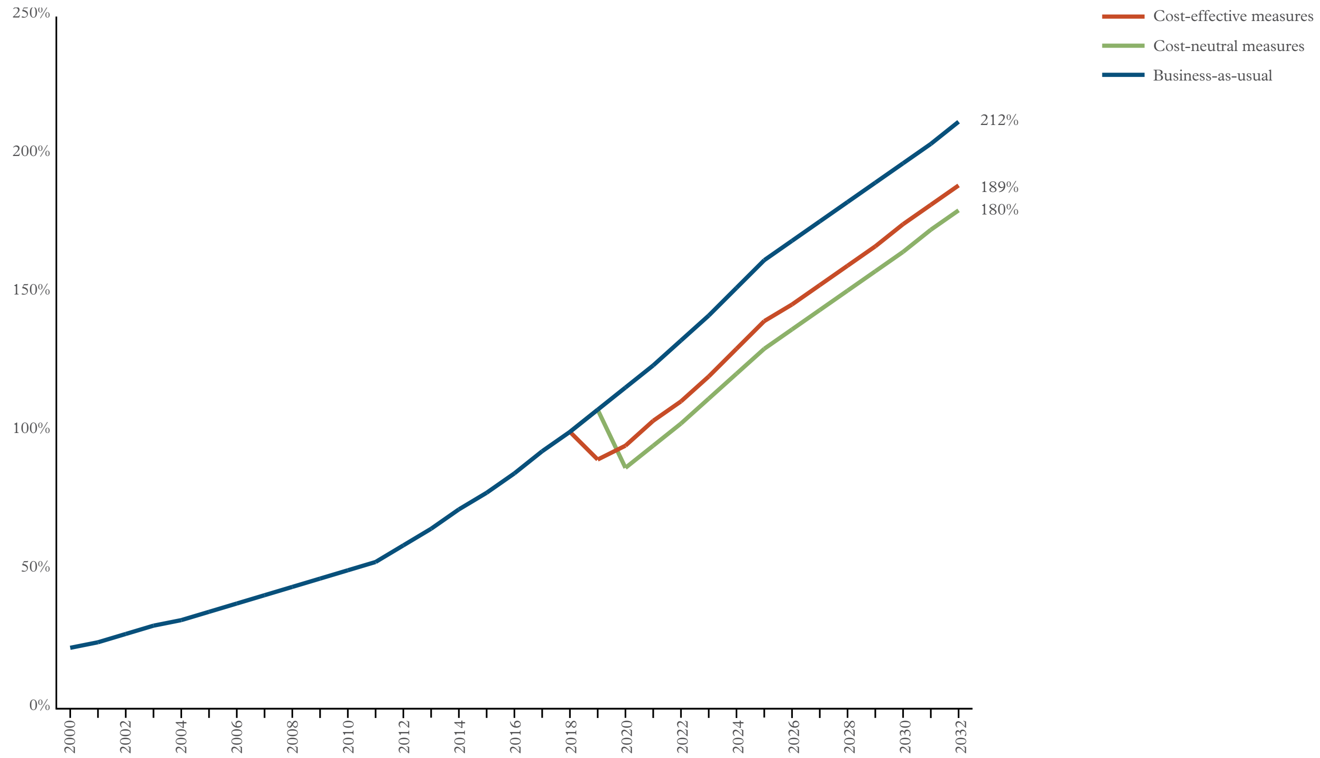
Figure 19: Indexed energy consumption, energy bills and emissions in the transport sector in Kigali between 2000 and 2032.



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)	-$397	-341,031
2	Bike lane investments (public case)	-$387	-332,417
3	Electric bike - 5% of trips 2032 (public case)	-$368	-316,774
4	Import age restrictions <15 (public case)	-$179	-153,664
5	Import age restrictions <10 (public case)	-$78	-67,073
6	Euro IV standards (public case)	-$36	-31,112
7	Bus network expansion - doubling of 2015 capacity by 2032 (public case)	-$26	-22,784
8	Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (public case)	-$15	-13,302
9	Parking meters in CBD (private case)	-$3	-2,872
10	Import age restrictions <10 (government case)	$0	0.0
11	Euro IV standards (government case)	$0	0.0
12	Import age restrictions <15 (government case)	$2	1,847
13	Bus network expansion - doubling of 2015 capacity by 2032 (private case)	$41	35,357
14	Bus network expansion Euro IV- doubling of 2015 capacity by 2032 (private case)	$42	36,483
15	Bike lane investments (private case)	$46	39,158
16	BRT Line 1 - CBD to Rusuoro (private case)	$206	177,552
17	BRT Line 2 - CBD to Gahanga (private case)	$247	212,531
18	BRT Line 1 - CBD to Rusuoro (public case)	$510	439,016
19	BRT Line 2 - CBD to Gahanga (public case)	$551	473,996

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)	971
6	Euro IV standards (government case)	971
7	Import age restrictions <10 (public)	655
8	Import age restrictions <10 (government case)	655
9	BRT Line 1 - CBD to Rusuoro (public case)	233
10	BRT Line 1 - CBD to Rusuoro (private case)	233
11	Electric bike - 5% of trips 2032 (public 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

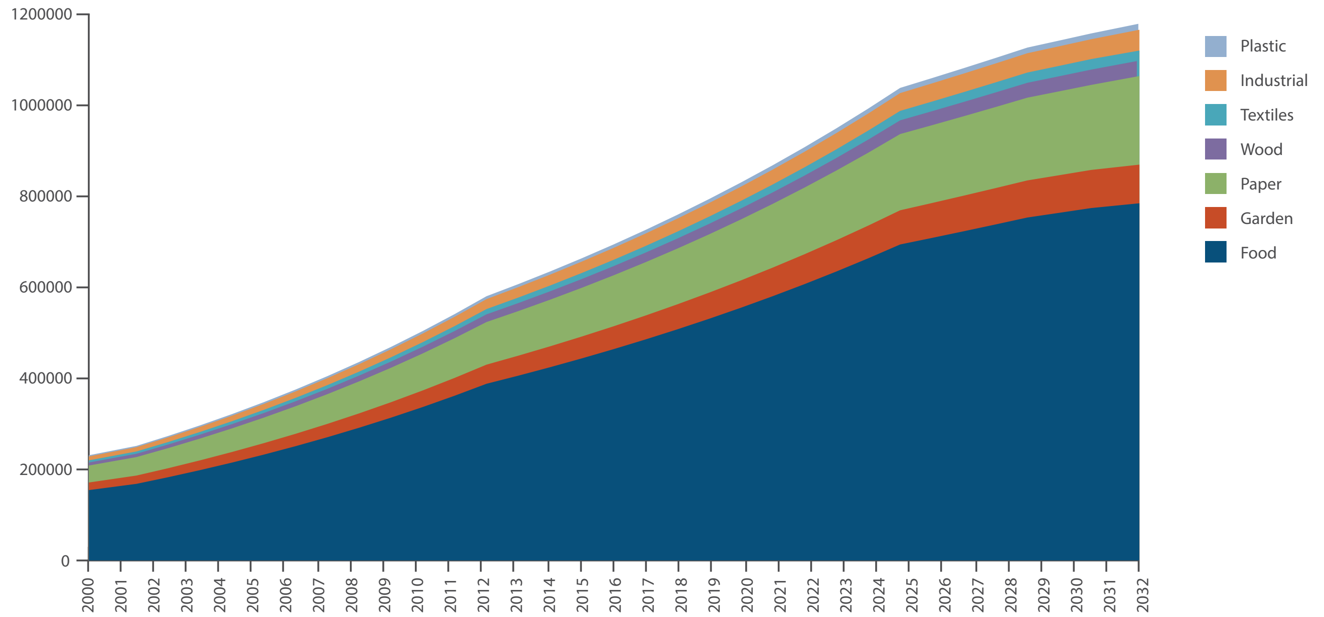
Population and economic growth are leading to a significant increase in waste generation in Kigali. Waste generation today is approximately 1.8kg/per capita/day, but it is projected to rise to 2.0kg/per capita/day by 2030 (REMA, 2013) and will exceed 1 million tonnes per year by 2020. We note that the solid waste management strategic plan has lower estimates of per capita waste production (City of Kigali and BTC Rwanda, 2012).

Food waste currently accounts for two-thirds of all waste production and 67% of all waste is disposed in landfills. The remainder is either burned or informally disposed. We assume that the composition of waste in the city remains the same to 2032, as this variable typically does not change much as a country moves from low- to middle-income status (World Bank, 2012).

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 highlight the need to develop an integrated waste management system as a priority area for government.

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). They 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 2032 BAU levels – 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 12.2 billion (USD 14 million), generating annual savings of RWF 3.9 billion (USD 4.5 million), paying back the investment in 3 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 419 ktCO_2e in 2018 to 805 MtCO_2e in 2032, an increase of 192%.

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

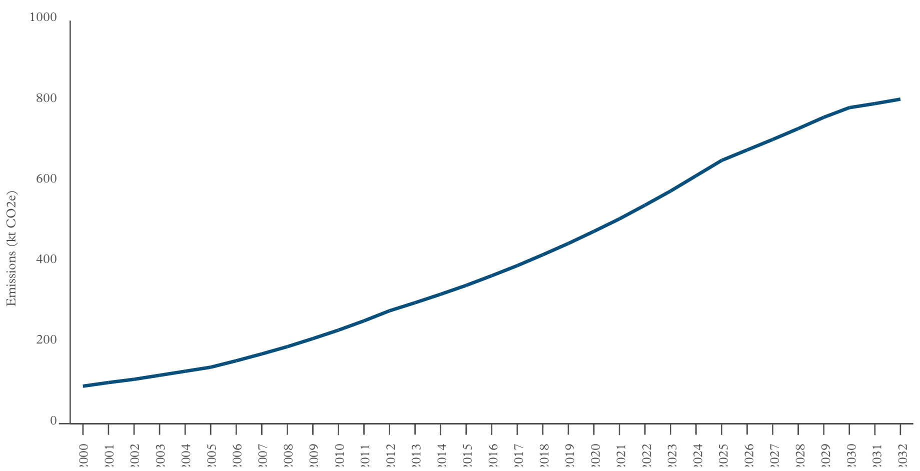
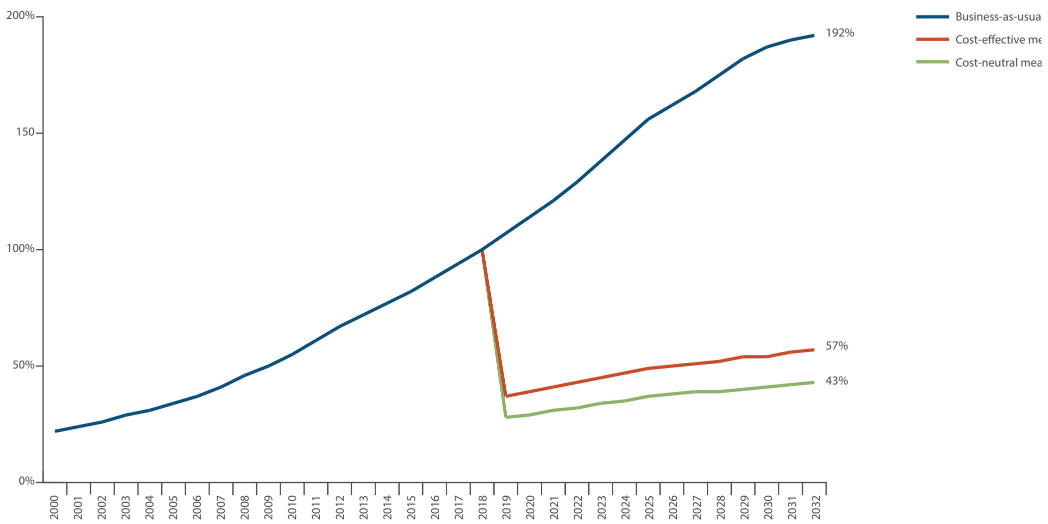


Figure 23: Emissions from the waste sector under three different investment scenarios, indexed against 2018 emissions, between 2000 and 2032.



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	- 4,477
2	Home composting (30%)	2	1,390
3	Home composting (15%)	2	1,459
4	Landfill gas flaring (65%)	3	2,839
5	Centralised anaerobic digestion to electricity	4	3,563
6	Landfill gas flaring (25%)	8	6,515
7	Home biogas production	10	8,487
8	Central composting (30%)	37	31,397
9	Central composting (19%)	38	32,750
10	Recycling (20%)	147	126,002
11	Recycling (40%)	151	129,739

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	10,399
2	Landfill gas utilisation	7,734
3	Landfill gas flaring (65%)	4,512
4	Landfill gas flaring (20%)	1,966
5	Home Biogas production	1,008
6	Central composting (30%)	694
7	Home composting (30%)	694
	Central composting (19%)	588
8	Home composting (15%)	575
9	Recycling (40%)	182
10	Recycling (20%)	91

Chapter 6. Discussion

Between 2000 and 2018, 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 140% by 2032 over 2018 levels.

The most significant source of new emissions comes from the transport sector, where emissions are projected to increase to 0.6MtCO_2 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 210%, or more than threefold, by 2032. While domestic energy sources, including expanding natural gas extraction 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, climate-resilient 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 7 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 8 years. These results reinforce the findings from the 2016 analysis, while the economic case for investment is slightly diminished due to lower fuel prices in specific cases, the overall case for action remains strong.

Further, these results emphasise that development priorities and climate action can be mutually supportive. Investments in the bus network can reduce emissions while help to improve the mobility of the urban poor, solar water heaters, low energy light bulbs, and clean cook stoves can cut energy expenditure while improving comfort, security and health, and investments in low carbon electricity sources can cut emissions while improving energy security. Achieving the goals of Rwanda's Vision 2020, Economic Development and Poverty Reduction Strategy II (EDPRS) and the targets of the Sustainable Development Goals, can thereby be furthered by approaches that explicitly acknowledge that a low carbon future for Kigali can also be a future that supports a wider set of development objectives.

However, it is critically important that these overlaps not be taken for granted. Actions to reduce poverty and meet the Sustainable Development Goals will, at times necessarily, lead to higher emissions. Where opportunities to reduce emissions and address wider priorities, including reducing poverty, increasing economic growth and improving resilience, exist, what can policymakers do to support these actions? A focus on the transport sector allows for a deeper analysis.

Discussions with firms (bus operators), investors (electric motorbike company Ampersand), and single operators (moto drivers), reveal that the challenges facing transport firms considering low carbon options in Kigali have strong similarities with the challenges that are highlighted by investors in urban developing contexts more widely. Importantly, lack of awareness about innovative technologies and opportunities is rarely a primary issue. Instead, a set of financial and non-financial barriers stand in the way of low carbon investments.

Financial barriers: Improving access to capital

Insufficient access to capital, or access that is at prohibitively high rates, constitutes one of the most significant barriers to investments of all kinds in developing contexts. Moto drivers in Kigali, for example, pay effective interests of more than 100% annually, making it challenging for them to purchase their own bikes, or make other investments in their businesses.

Direct action, in the form of targeted grants, low cost loans and tax abatement schemes from the government can a play a role where private sources of finance are constrained in what they can invest in, or unable or unwilling to take on risk. One example of direct support currently operating in Rwanda is The Fund for the Environment and Climate Change (FONERWA), which provided more than 10 grants to private actors for climate change and environmental initiatives over the last year (FONERWA, 2017).

Expanding such support at the urban level can play a role in addressing businesses need for capital by providing 'proof-of-concept' for low carbon investments. However, targeted government interventions of this kind are unlikely to be a scalable long-term solution. Instead, policymakers need to consider how they can support the foundations of private finance in Kigali.

On the 'demand' side, lack of business planning and knowledge can make it challenging for private sources of capital to provide finance. The Private Sector Federation of Rwanda, an industry group that has formed a partnership with the national government to train small and medium-sized businesses to explore financial opportunities around climate change provides a support for business plan development, has played an important role in this context (PSF, 2016). Similar programs elsewhere in sub-Saharan Africa have found significant impacts at a relatively low cost (Mano et al., 2012)

On the 'supply' side, The City of Kigali can improve its own capacity to provide credit and act as an active investor, a role that is particularly important in the transport sector. In the housing, commercial, industrial and waste sectors investments frequently provide financial returns that accrue to the investor. By contrast, the returns for large public transport investments are often diffuse and challenging to monetize. Indeed, the 'co-benefits', rather than the direct financial benefits, are typically the primary justification for public transport investments. Recent research emphasises the far-reaching benefits of low-carbon multimodal transport networks, arising from improved mobility, increased employment opportunities, reduced congestion, improved social inclusion, increased traffic safety and improved air quality (Gouldson et al 2018)

Improving a city's credit capacity, by increasing own source revenue, expanding the tax base, establishing titles for landholding, and improving systems of governance (among other interventions), cannot be achieved overnight. But that does not mean innovative programs and policies cannot yield substantial benefits. In Kampala, for example, the city tripled tax revenue over 5 years after investing in Kampala invested in eCitie, software which allows payments for business licences, hotel taxes, ground rents, property rates and market charges over mobile phones.

Removing non-financial barriers

Investment risks can be financial, relating, for example, to interest and exchange rates, business models and energy prices. But the risks that discourage investment can also be non-financial, including uncertainties around new technologies, government policies and legal codes. For newer technologies and innovations, relatively larger opportunities for impact and investment returns are often faced with relatively larger risks.

One example in Rwanda is the opportunity for electric motorbikes. Motorcycle taxis, or 'motos', are currently used for approximately 16% of trips in Kigali, generate approximately one-fifth of transport related carbon emissions and account for a similar proportion of energy expenditure. By 2032 the number of trips and volume of emissions and expenditure on energy are expected to more than double. At the same time, motos may be a significant contributor to rising air pollution in the city due to the fact that most vehicles would be unlikely to comply with air quality regulations in wealthier cities.

Shifting a proportion of these conventional motorbikes to electric motorbikes would not only improve air quality and reduce carbon emissions, it would also generate economic benefits. While an electric bike and reserve battery are approximately the same price as a conventional moto, the costs of operation are radically different: A typical moto drive travelling 190km a day would spend approximately 4500 RWF (5 USD) on fuel each day while an electric moto driver would spend less than 1700 RWF (2 USD), leading to massive savings over time (especially considering moto drivers relatively low wages).

Electric motorbikes to date have received limited uptake in Kigali, and to the largest extent this can be attributed to the novelty of the technology and a focus of electric motorbike firms in markets that are larger and that they perceive as more lucrative. At the same time, a number of non-financial barriers could also be playing a role.

Delays at customs are said to require as many days as shipping electric motorbikes from China to Dar es Salaam (35 days) and then to the border by truck (5 days). Licencing requirements for electric moto drivers are uncertain and require coordination between the Rwanda Revenue Authority and the Rwanda National Police (which are responsible for vehicle registration and issuing license plates respectively). Similarly, new regulations around charging infrastructure will need to be developed by the City of Kigali. Importing vehicles as parts to be assembled rather than completed motorbikes carries a lower tariff, but a workforce that is knowledgeable about electric motorbikes is needed.

Importantly, these challenges are for the most part neither unique to Rwanda nor to electric motorbikes. Rather, these challenges as the same ones many governments are facing globally in the face of technological advancement and a globalising economy. In this context, both Rwanda and Kigali can learn from best practices of neighbours and other countries facing similar challenges. On improving customs procedures Rwanda may be able to learn from Tanzania, where the Tanzania Customs Integrated System (TANCIS) has helped to streamline customs procedures. And for challenges that are specific to electric mobility, the UN E-Mobility program has set aside funds in order to help countries in the East Africa Community (EAC) to pilot electric vehicles and formulate new policies.

Chapter 7. Conclusion and Recommendations

Rapid development in Kigali is leading to rapid increases in per capita energy use and emissions even as the city's population continues to grow. Although economic growth is anticipated to decouple from emissions in relative terms, a continuation of business as usual trends will lead to steady increases in energy use, energy bills and emissions. This path will not only increase Kigali's dependence on foreign energy, but has consequences for social equity and liveability in Kigali as energy costs and pollution levels rise.

This research reveals that there are many economically attractive opportunities to investment in low-carbon, climate-resilient development 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 and climate-resilient 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, climate-resilient investment helps to build public interest in, and unlock new finance streams for, ambitious climate action in Kigali

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 Planner	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. Emissions factors

	Net CV	Gross CV	Density	Density	Net CV	Gross CV
	GJ/tonne	GJ/tonne	kg/m3	litres/tonne	kWh/kg	kWh/kg
Diesel	42.9	45.7	8375	1194.0	11.9	12.7
LPG	46.0	49.3	508.2	1967.8	12.8	13.7
CNG	47.7	53.0	175.0	5714.3	13.3	14.7
Natural gas	47.7	53.0	0.7	1340651.0	13.3	14.7
Petrol	44.7	47.1	734.0	1362.0	12.4	13.1
Biodiesel (ME)	37.2	41.0	890.0	1124.0	10.3	11.4
Biodiesel (BtL or HVO)	44.	46.3	780.0	1282.0	12.2	12.9
Bioethanol	26.8	29.3	794.0	1259.0	7.4	8.1
BioETBE	36.0	39.6	750.0	1333.0	10.0	11.0
Biogas	30.0	33.3	1.0	1038840.0	8.3	9.3
Biogas	49.0	54.4	0.7	1376907.1	13.6	15.1

Transport fuel	tCO2-e/kL (tco2-e/m3 CNG)
Petrol (100% mineral petrol)	2.3144
Bioethanol	0.0057
Diesel (100% mineral diesel)	2.6769
Biodiesel	0.0175
Compressed Natural Gas (CNG) t/m3	0.0023400

Appendix C. Additional information on the electricity sector

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: The fuel properties can be used to determine the typical calorific values/densities of most common fuels. Source: Defra (2013).

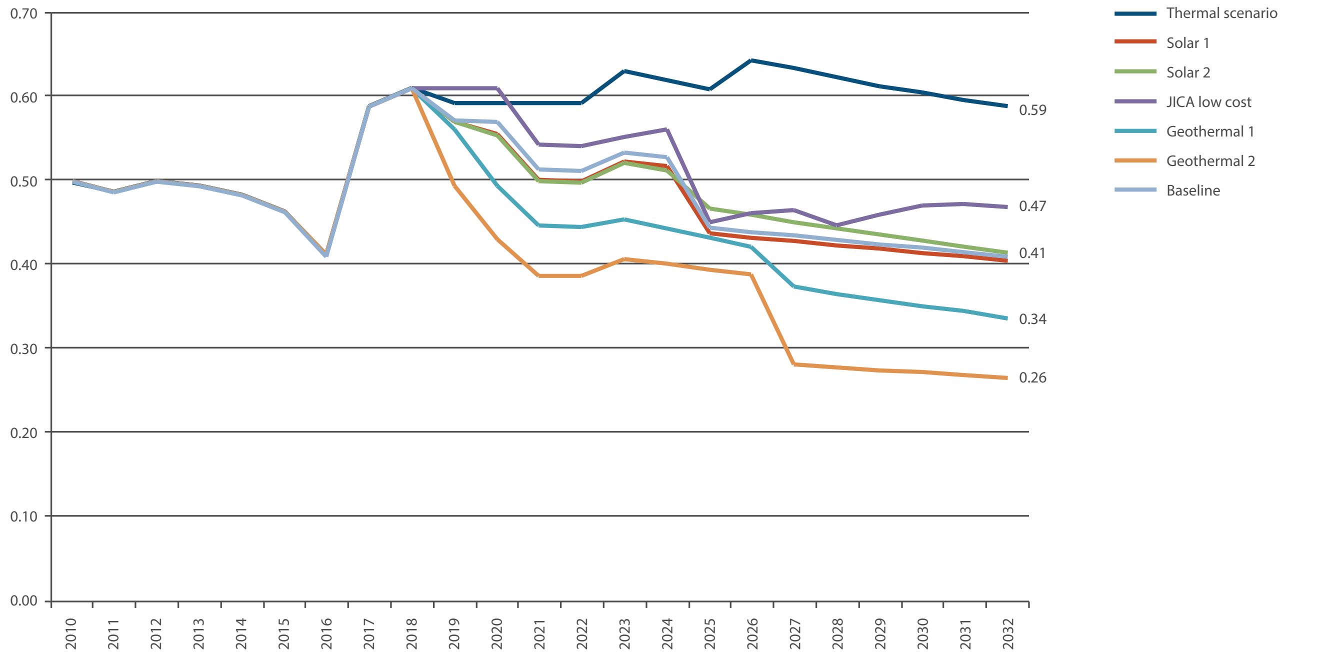
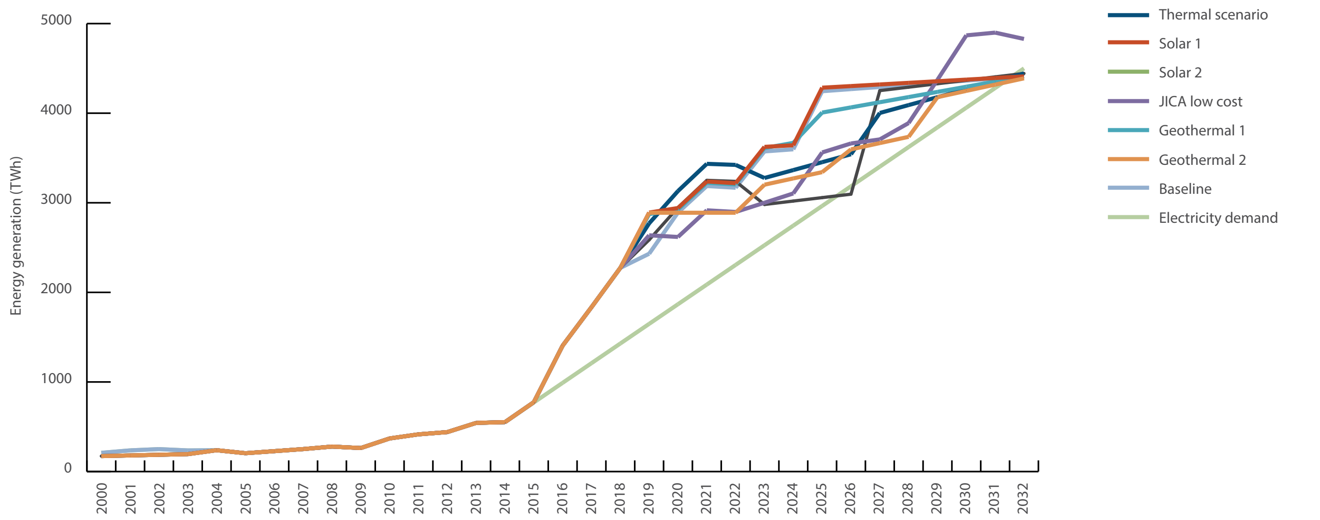
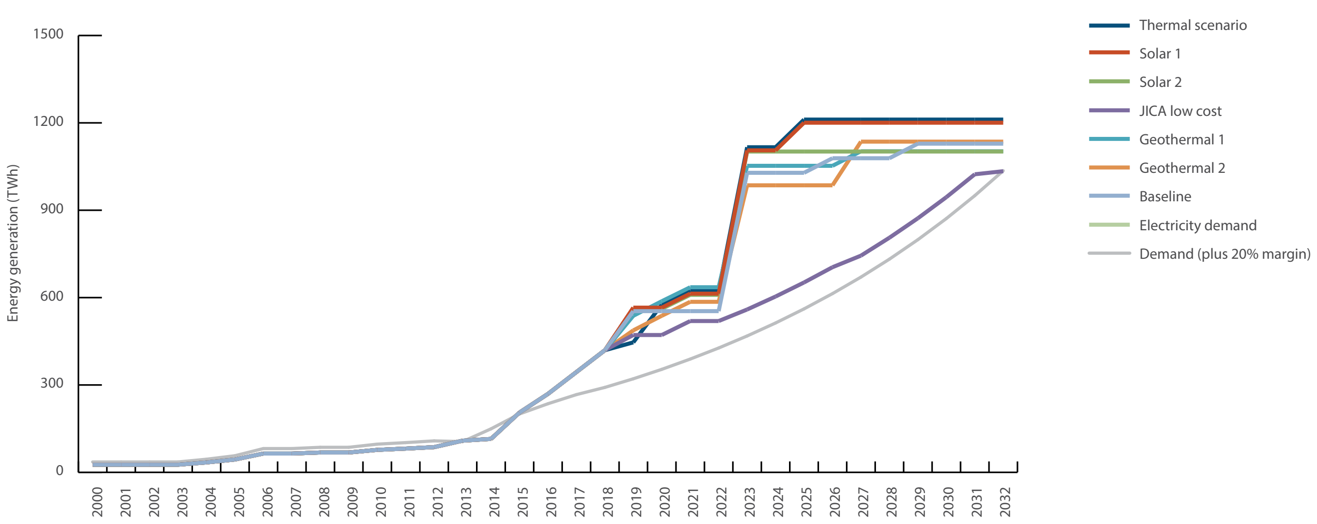


Figure 25: The fuel properties can be used to determine the typical calorific values/densities of most common fuels. Source: Defra (2013).



Continued.

Figure 26: Emissions factor for each scenario, 2015-2032.



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

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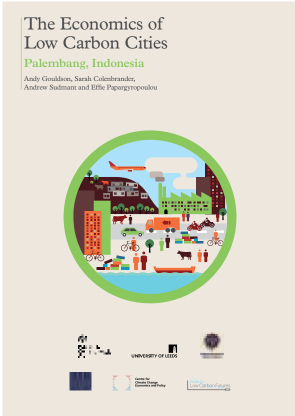

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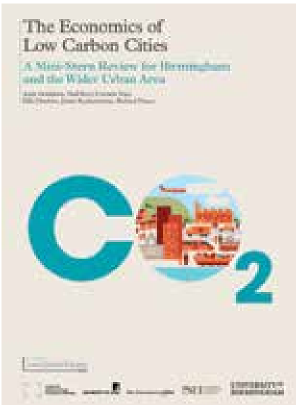

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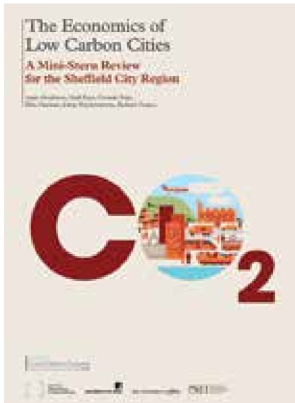

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