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Assessing impacts of energy efficiency policies on the future energy demand in secondary cities in Rwanda,

case study of Musanze

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DECLARATION AND CERTIFICATION

Declaration

I, Jean Damascene NIYONZIMA, master student, registered under, PAUWES/2017/MEP13, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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Certification

This is to certify that the master's thesis entitled **"Assessing Impacts of Energy efficiency Policies on Future Energy Demand in Secondary Cities in Rwanda, Case study of Musanze"** is a record of the original bona fide work done by Jean Damascene NIYONZIMA. This thesis is the candidate's original work and has been prepared with our guidance and assistance. Therefore, it is certified for submission as final version done with our approval as official University supervisor, and all corrections were added as recommended by the examination committee

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ABREVIATIONS AND ACRYONYMS

BAU: Business As Usual

EDPRS: Economic Development Poverty Reduction Strategies

EE: Energy efficiency

EES: Energy efficiency Scenarios

GDP: Gross Domestic Product

GGGI: Global Green Growth Institute

GJ : Gigajoule

GPL : Gaz Petrolier Liquefié

GWh: Gigawatt-hour

IEA: International Energy Agency

KWh: Kilowatt-hour

LEAP: Long Range Energy Alternatives Planning System

LPG: Liquified Petroleum Gas

MININFRA: Ministry of Infrastracture

MINIRENA: Ministry of Natural Resources

MW: Megawatt

NISR: National Institute of Statistics of Rwanda

REG: Rwanda Energy Group

REMA : Rwanda Environnent Management Authority

RHA: Rwanda Housing Authority

RSB: Rwanda Standards Board

RURA: Rwanda Utilities and Regulatory Authority

UNDESA: United Nations Department of Economic and Social Affairs

Abstract

Urbanization is occurring fastest in developing countries, with the least developed countries expected to have the highest population growth rates. Cities in these countries are going to increasingly be important sites of energy demand. Potential future developments of energy efficiency in developing urban areas and their impact on natural resources are often neglected. Rwanda has ambitious targets to hook up thousands of households to the energy access each year, and with the high projected economic growth forecast for the country, demand for electricity by all economic sectors in Rwanda will almost certainly increase for the foreseeable future. Energy efficiency is the key driver to meet with future demand. The purpose of the study is to assess the impact of energy efficiency policies on future energy demand in secondary cities. Modeling and scenario techniques through LEAP (Long Range Energy Alternatives Planning System) software to predict the future energy demand. The results showed that four energy sources predominate: electricity, charcoal, firewood and LPG. However, there were urban households with greater diversity of energy sources in urban households, also including electricity (97.89%), candles (44.21%) and liquefied petroleum gas, or LPG (37.89%). Charcoal use is much higher at 82.11%, whereas firewood use is only 29.49%. The demand of modern fuels such as LPG, kerosene and electricity are increasing, and the analysis shows that the demand of both LPG and electricity would increase significantly. At Energy Efficiency Scenario will be led by mordern fuels at rate of 66.9% where LPG will have 47% total demand and electricity with share of 19.9%. This study showed that with effective implementation of the energy efficiency policies would save about 27.5% of energy and reduce energy fuel demand in 2040. In order to minimize energy loss in urban households, this research suggests that similar studies in the future may focus more on obtaining previous data, if possible, the study could be conducted over years to use own primary data, or else obtaining as many years' data as possible to forecast the future energy consumption accurately.

Keywords: Energy efficiency, Scenarios, Forecasting, secondary cities

Résumé

C'est dans les pays en développement que l'urbanisation est la plus rapide, les pays les moins avancés devant connaître les taux de croissance démographique les plus élevés. Les villes de ces pays vont devenir des sites de plus en plus importants pour la demande énergétique. Les développements potentiels futurs de l'efficacité énergétique dans les zones urbaines en développement et leur impact sur les ressources naturelles sont souvent négligés. Le Rwanda s'est fixé des objectifs ambitieux pour raccorder chaque année des milliers de ménages à l'accès à l'énergie et, compte tenu de la forte croissance économique prévue dans le pays, la demande d'électricité de tous les secteurs économiques du pays augmentera presque certainement dans un avenir proche. L'efficacité énergétique est le facteur clé pour répondre à la demande future. L'objectif de l'étude est d'évaluer l'impact des politiques d'efficacité énergétique sur la demande énergétique future dans les villes secondaires. Modélisation et techniques de scénarios à l'aide du logiciel LEAP (Long Range Energy Alternatives Planning System) pour prédire la demande énergétique future. Les résultats ont montré que quatre sources d'énergie prédominent : l'électricité, le charbon de bois, le bois de chauffage et le GPL. Cependant, il y avait des ménages urbains avec une plus grande diversité de sources d'énergie dans les ménages urbains, y compris l'électricité (97,89%), les bougies (44,21%) et le gaz de pétrole liquéfié, ou GPL (37,89%). L'utilisation de charbon de bois est beaucoup plus élevée à 82,11 %, alors que l'utilisation de bois de chauffage n'est que de 29,49 %. La demande de carburants modernes tels que le GPL, le kérosène et l'électricité augmente, et l'analyse montre que la demande de GPL et d'électricité augmenterait considérablement. Au Scénario d'efficacité énergétique sera mené par les combustibles mordern au taux de 66,9% où le GPL aura 47% de la demande totale et l'électricité avec une part de 19,9%. Cette étude a montré qu'une mise en œuvre efficace des politiques d'efficacité énergétique permettrait d'économiser environ 27,5 % de l'énergie et de réduire la demande de combustibles énergétiques en 2040. Afin de minimiser les pertes d'énergie dans les ménages urbains, cette recherche suggère que des études similaires pourraient à l'avenir se concentrer davantage sur l'obtention de données antérieures, si possible, l'étude pourrait être menée sur plusieurs années pour utiliser ses propres données primaires, ou bien obtenir autant de données que possible pour prévoir avec précision la consommation énergétique dans le futur.

CHAP I. INTRODUCTION

1.0. Background

Current years, the energy consumption in urban areas has brought important studies, moreover the impacts of generating decentralized renewable energy and a demand-side strategy towards greenhouse gases emissions reduction are major factors to urban energy planning goals (Collaço et al., 2019). Nowadays, the world is facing excessive population density mostly in least developing and developing countries as urbanization is arising at high rate between 2010 and 2050 (Madlener & Sunak, 2011). Energy demand in urban areas is crucial sector going to increase in the future. Any country to achieve development and standard life, energy consumption has been regarded as a standout amongst the most unswerving indicators It is important to predicting future energy demand which is foundation for energy planning(Cormio, Dicorato, Minoia, & Trovato, 2003)

According to IEA report 2018, after two years of small evolution, worldwide energy demand raised by 2% in 2017. Current progress on energy efficiency were more significant as result of rising up of end use energy activities across many countries, regions and sectors offset ongoing progress on energy efficiency. Global energy intensity dropped by 1.7% in 2017, the least annual improvement this decade. Nevertheless, the world would suffer from abundant energy demand, if there is no progress on energy efficiency. Over last years, efficiency policies have indicated significant impacts, where globally, since year 2000 energy consumption reduced about 12% energy use that would have used without energy efficiency in the case in 2017(IEA, 2017). In most city areas all over the world, energy demand is keeping to increase a lot. Over 50% of the world's population now dwells in urban areas, however these cities are consuming approximately 75% of energy use. As these urban residents continues going up, there will affect entire worldwide energy demand and the resultant carbon emissions (Nakicenovic et al., 2012).

Sub-Saharan Africa currently has 13% of the world's population but is only responsible for 4% of its energy demand – and much of this demand is from traditional biomass fuels(IEA, 2014a). Because of this relatively low energy demand per capita, and the fact that much of it is from biomass, sub-Saharan Africa is typically considered a relatively small contributor to future global energy demand and carbon emissions (IEA, 2014). The future energy demand of Sub-Saharan Africa is likely to be significantly urban, over 75% by 2040 will be the city share of total demand rising to over 75% by 2040. Universal access to modern energy and energy efficiency implementation, as proposed in the Sustainable Energy for All goals, could reduce energy demand by 17% by 2040(SEA, 2015).

In developing countries like Rwanda, biomass takes high share of the total energy consumption, it has 85% of all energy demand. Most of biomass is mainly used for cooking, with wood and charcoal used respectively by rural and urban households(MININFRA, 2018). Residential sector is the first dominant of energy consumer, with 82%, followed by transport with 8%, industries at 6% and others sectors at 4% (MININFRA, 2018). The researh done on future energy projection the results showed that, by 2050, the total electricity demand would get 6,546 GWh for the very low scenario, 8,100 GWh for the very likely scenario and 10,240 GWh for the very high scenario instead in 2012 was 379 GWh. Under the BAU supply scenario, the national energy resources will only be able to satisfy the demands under the very low and very likely scenarios. Under the very high scenario to satisfy the demand, above 20% of electricity needs would depend on imported fossil fuels. By 2050, under the proposed alternative scenario, nevertheless, there would be no need of importing fossil fuel. (Uhorakeye, 2016).

Internationally there have been several studies conducted that have used LEAP as a tool for city-level modelling of impacts of different scenarios on energy, economic and environmental indicators. About modeling of energy consumption particularly in residential sector. Taking Tehran, Iran as a case study, (Abbaspour et al., 2013)studied about previous trend and future consumption projection. They identified the possible projection of consumption of various fuels and also analyzed the possible amount of energy that could be saved if policy implication is conducted. (Phdungsilp, 2010) investigated the energy needs and emissions of Bangkok with the goal of identifying the implications of different policy scenarios on the energy mix of the city. LEAP was applied by the Energy Research Centre and Sustainable Energy Africa to design an energy model of the city of Cape Town in South Africa and to help the Cape Town Energy and Climate Action Plan (SEA, 2010). The model revealed that, at present trends, the urban demand will use four times as much energy by 2050. An optimal energy future scenario was simulated, which joined an involvement of all sectors (transport, industry, household and commercial). The optimal energy scenario cost was only slightly above the business-as-usual scenario but had a major energy reduction by 2050.

1.1. Problem statement

Due to the estimated increase in economic activities, electrification rate and demographic growth in Rwanda, more sufficient energy supply would be needed to meet the future raising demand. Rwanda has ambitious targets to develop green secondary cities that will contribute reaching urbanization 32% by 2018 and 35% by 2020, respectively goals set by EDPRS 2 and Vision 2020(Government of Rwanda and GGGI, 2015)

The shortage investments in the energy has made Rwanda face an energy scarcity last two decades. With the growing of the economic activities and increasing industries in urban areas, energy provided by existing hydro and thermal power plants has been progressively scarce with high-pitched energy prices, and energy instability (Safari, 2010).

Last five years ago, Rwanda's economy growth has been at an average rate of 7.2%. consequently, annual demand for electricity is rising around rate of 8%. Building new power plants should be added to the existing system to satisfy the energy end user demand. Due to continuous rise in energy consumption has not solely brought economic issues on the country, however additionally raise the problems of energy security and sustainable development(MININFRA, 2018). In urban areas in Rwanda, as in other developing countries, there has been an intense growth rate of energy consuming electronics and electronic appliances, most studies however have given less attention for the rising in energy consumption due to appliances. The main issue that is addressed in this study is the lack of energy urban planning in secondary cities for demand forecasting.

Thus, it is necessary to have reliable energy demand projections are a fundamental criterion for supply side planning of developing urban areas. Because of the restricted energy resources, so that efficient energy use turns out to be very critical. It is also needed to change the current energy consumption mix dominated by traditional and imported fuels to a more desirable energy mix having higher share of local clean renewable energy resources. For this purpose, first the prediction of actual demand of the demanding fuels are necessary and afterwards, the essential policy measures can be formulated to path the future national energy supply system of the country.

1.2. Objectives

The main objective of the project is to evaluate and analyze impact of energy efficiency policies on future energy demand in secondary cities. Apart from the main objective, following are the specific objectives of this study:

- To evaluate energy resources, energy development and associated policies in Rwanda,
- To develop the long-term energy scenarios for secondary cities,
- To forecast energy savings resulting from the energy efficiency policies,
- To recommend sustainable energy policy alternatives that can improve the energy situation in secondary cities using energy efficiency.

1.3. Research questions and hypothesis

This thesis presents three research questions:

- How will energy demand in the secondary cities develop without national energy efficiency planning and policies?
- How could adopting energy efficiency policies affect the future energy demand in secondary cities?

Working Hypothesis:

The growing development in energy efficiency technological interventions, the application of these technologies is not great enough to show that there is a significant future energy consumption reduction.

1.4. Methodology

This study will be carried out in Rwanda. Mainly in the secondary city of Musanze. It will involve the quantitative and qualitative research methods will be used to collect and analyze data related to household energy consumption patterns and avenues for participation in energy planning. The purposive sampling technics and focused group will be used to gather, the primary data, using interview, questionnaire, and direct observation, while the secondary data will be gathered using government report and official website.

The final energy demand of the secondary cities in Rwanda will be determined by adding energy demands of residential. The demands of the residential sector are determined through end use methodological approach on the base year 2012 and data collection from survey, and further projections of the demand are based on the function of population, GDP per capita, and corresponding economic sectoral value added of the secondary cities.

The review of the existing energy forecasting models and literatures applying the LEAP model. This will be done to explore the characteristic features of the existing energy forecasting models and to establish a basis for the selection of the model that was used in this thesis. The literature review examines the scholarly contributions in the energy demand modeling literature that applied the LEAP model to various residential and commercial sectors in different countries. The 3 policy scenarios (one reference scenario and 2 alternative scenarios) for the secondary cities LEAP model will be developed. The developed policy scenarios were projected from the base year, 2012, to the target year, 2040. This will be made by considering various parameters that can alter the energy system in the future: GDP, income, population, household size, and sector growth rate. The forecast includes the energy demand and supply, electricity demand and supply (including capacity expansion), and costs and benefits.

1.5. Significance of your study

In implementing Sustainable development Goals and Africa Agenda 2063, Rwanda has ambitions to attain energy security and a low energy intensity that helps the development of green industry and services and avoids deforestation. The pathways derived from the analysis, which detail how the energy efficiency in Rwanda’s secondary cities may develop over a long-term time horizon, provide additional information that helps energy policy makers define guidelines and strategies for policies to shape the country 's energy sector.

There is increase in financial gain can facilitate the dwellers to possess additional appliances with larger size, that has more power ratings. Having various individuals with different income level and standard living, it is extremely vital to perform studies on this energy consumption and appraise future energy consumption figures based on mostly numerous scenarios. This study result will help to provide an energy policy that meets the demand and to analyze the energy saving choices within households.

The result of this research could be useful the following ways:

- Based on research findings die policy makers will be able to make more informed decisions by knowing the nature of the relationship between energy efficiency, environment and economy.
- The energy policy researchers could also apply this knowledge to shape further future energy policy,
- Stakeholders of the energy sector may find it an important strategic tool to which extent and ways to involve in the energy project development,

1.6. Thesis chapter outline

Chapter1covers the introductory information including background, problem statement, motivation, objective and scope of the study. Chapter 2 provides a literature review which will illustrate the background of the energy demand in the case study area, reveals about previous works and energy modeling tools and also determine the parameters used in the selected long-term energy modeling tool. Chapter 3 explains about the methodology that means about the data collection and post processing of the data. Chapter 4 deals with the results of the statistical analyses and the energy modeling tool, primarily presenting the types of fuels and devices like stoves being used in the selected households and differences in energy demand for different types of houses, the fuels, etc.; and secondly, presenting the results of the forecasting analysis for various types of scenarios. Chapter 5 delivers the conclusions of the study and provide recommendations for further research.

CHAP 2. LITERATURE REVIEW

This chapter presents an insight into the Rwanda energy sector, energy efficiency policies, the energy efficiency benefits, various energy forecasting models, their approach and classification. It also highlights some scholarly contributions in the energy economics literature which applied the LEAP model on various sectors in different countries of the world.

2.1. Introduction

Energy is the vital fuel for economic and social development, and energy efficiency policies enhance development, by rising the number of activities services got from every unit of energy. Using energy efficiency can reduce demand, boost power capacity and the reserve margin. Executing energy efficiency practices can be thought of as adding a virtual power plant. (IEA, 2014b). There is a critical need to help developing countries meet their growing energy needs in order to maintain robust socioeconomic development. The recent volatility of oil prices and current projections show an increased reliance on oil and gas, and have collectively heightened concerns over energy security issues (IEA, 2014b).

Energy efficiency is rapidly becoming a critical policy tool a. round the world to help meet this substantial growth in energy. Evidence from the past 3–4 decades of experience around the world indicate that energy efficiency programs generally entail positive and multiple benefits for the government, energy consumers and the environment. (IEA, 2014b).

2.1.1. Key terms and concepts

The key terms related to energy efficiency and energy savings, which are used in this report, are defined as follows in Article 2 of Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency:

- ‘**Energy efficiency’** means the ratio of output of performance, service, goods or energy, to input of energy;
- ‘**Energy savings’** means an amount of saved energy determined by measuring and/or estimating consumption before and after implementation of an energy efficiency improvement measure, whilst ensuring normalisation for external conditions that affect energy consumption;

- ‘**Energy efficiency improvement’** means an increase in energy efficiency as a result of technological, behavioral and/or economic changes;
- ‘**Energy service’** means the physical benefit, utility or good derived from a combination of energy with energy-efficient technology or with action, which may include the operations, maintenance and control necessary to deliver the service, which is delivered on the basis of a contract and in normal circumstances has proven to result in verifiable and measurable or estimable energy efficiency improvement or primary energy savings;

Energy efficiency measures reduce the energy needed to produce the same quantity of goods and services or increase the output whilst keeping energy consumption constant. In addition to this direct contribution to improved competitiveness, energy efficiency measures provide indirect or ‘non-energy benefits’ that can increase the level of productivity. These include lower maintenance costs, higher levels of motivation, safer working conditions (IEA, 2012). The focus of this report is on end-use energy efficiency, ie measures that contribute to a reduction in energy demand, as opposed to measures that improve the efficiency of the energy supply chain.

Both direct and indirect energy efficiency benefits therefore affect competitiveness. Following Michael Porter from Harvard University, real competitiveness should be defined by productivity which in turn is a function of the value of goods and services (measured in price) and the degree of efficiency of their production (Porter 1990, see ECEEE 2013). In other words, productivity is defined by the relationship between the quantity of goods and services produced by a business or an economy and the quantity of labor, capital, energy, and other resources that are needed to produce those goods and services.

A commonly used measure in this context is the energy intensity of an economy which measures the energy consumption of an economy and its energy efficiency; it is the ratio between gross inland consumption of energy and gross domestic product. Energy intensity can therefore improve as a result of structural changes in an economy such as a lower share of energy-intensive manufacturing. Energy intensity can also be applied to individual sectors of an economy.

2.1.2. Challenges to quantify energy savings and related benefits and costs

Measuring and quantifying energy savings as a result of specific policy measures or programmes is challenging since it requires a comparison with the counter-factual, ie the energy that would have been consumed if the measure or programmes had not been implemented. Similar challenges apply to the quantification of benefits and costs and need to be taken into account when assessing those. While energy efficiency programmes produce a significant number of 'non-energy benefits', benefits are often evaluated only on the basis of the energy savings they deliver. This is due to the fact that 'non-energy benefits' are in general not quantified also due to the methodological challenges involved.
As a result, cost-effective energy savings potential tends to be underestimated (IEA, 2012). In addition, one needs to note that ex-ante estimates of costs to business of environmental legislation often (though not always) exceed the ex-post estimates by a substantial margin (Oosterhuis et al, 2006). Costs of energy efficiency measures are in general measured in terms of additional costs as compared to costs for a conventional technology.

2.2. Overview of Rwandan Energy sector

2.2.1. Country profile

Rwanda, is a small and landlocked country in East Africa with 12,089,721 (NISR, 2018) people on a total surface of 26,338 km^2, with 94.7% of it, land and the rest 5.3% is occupied by water (World Bank, 2012). Its geographical location is within latitudes 1.050 and 2.840°S, and longitudes 28.860 and 30.900°E (World Atlas, 2017), and has two rainy seasons in a year, which naturally feed the numerous rivers systems in the country. It is sandwiched by Uganda, Burundi, Tanzania, and Democratic Republic of Congo (World Bank, 2012; World Atlas, 2017). In recent years, Rwanda has attained rapid economic growth and is invested with substantial energy resources which have yet to be fully exploited (REG; RDB, 2018).

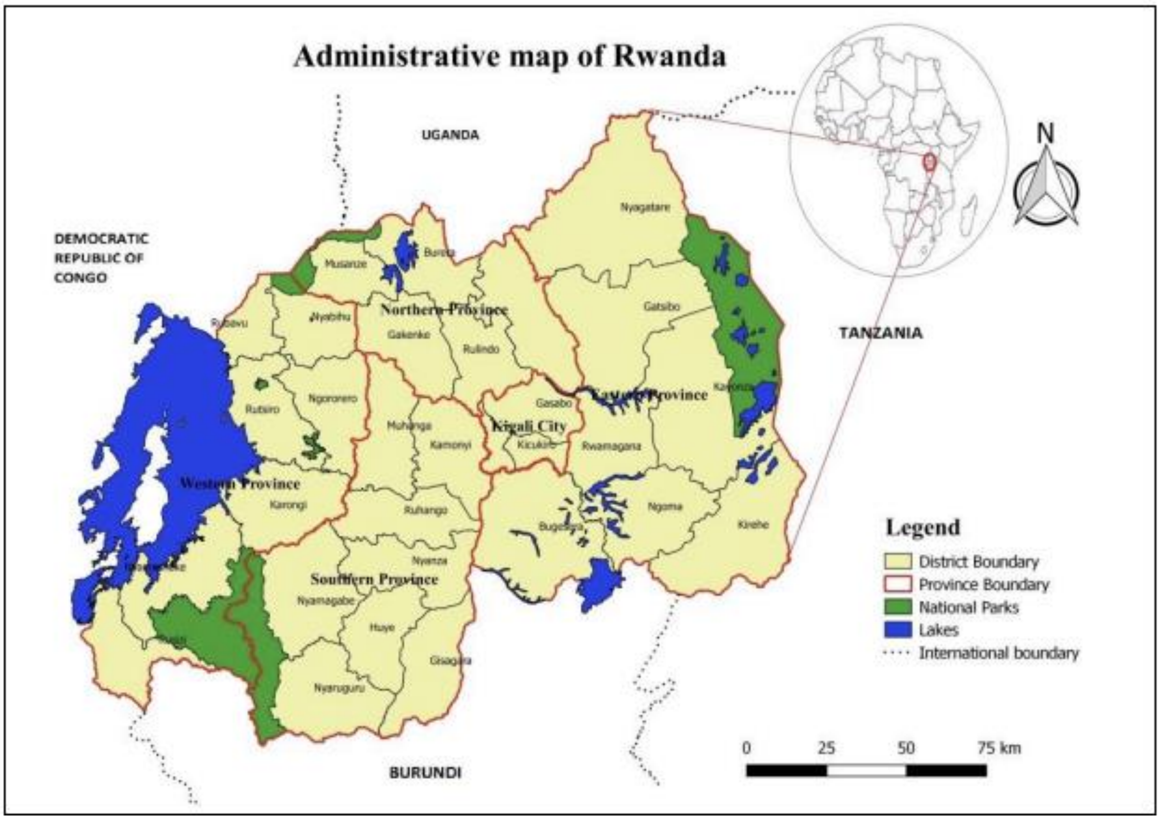

Figure 2.1. Map of Rwanda (source NSIR, 2018)

Although Rwanda has significant energy potential resources such as hydro, solar, geothermal, peat, gas, and biomass, currently, the total installed capacity to generate electricity in Rwanda is 221.1 MW from all the resources (REG, 2019). Despite admirable economic growth, it has a low per capita Gross Domestic Product (GDP) of US$ 720 and a low per capita electricity consumption (30 kWh) compared with neighboring Uganda (66 kWh), Kenya (140 kWh), and Tanzania (85 kWh) (Hakizimana et al., 2016; Munyaneza et al., 2016). Besides, paying the highest regional electricity tariff in that varies between US$0.12 and US$0.18/kWh (Hakizimana et al., 2016), to compare with the local Rwandan electricity tariff of US$0.22/kWh (REG, 2018c), it is found that Rwanda's electricity price is about 22.2% more expensive than the highest electricity tariff in the EAC.

About 55.1% of the population live under the poverty line in Rwanda, it is categorized as least developed country (LDC). Its economy is largely based on services and agriculture, which take about 10% 51.1% and 33.0% of GDP, respectively. Industry is less dominant and accounts for only 15.9% of GDP.

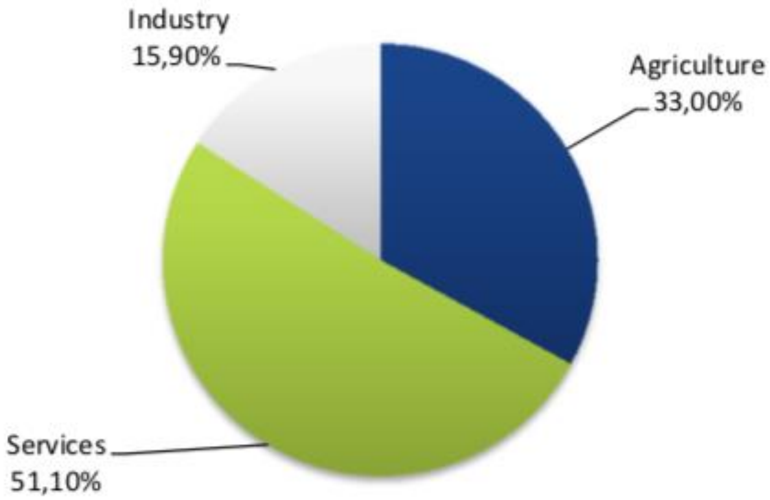

Figure 2.1: GDP distribution by sector

The main services sector contains banking, tourism, and transport, information and communications technology (ICT). International tourists to Rwanda have been rising at rate of 6% through latest years, and are playing a great significance to the Rwandan economy.

Around 80% of the work force from Agriculture employments, gathers 90% of national primary food needs and produces beyond 70% of the export revenues. The key export harvests are coffee, tea, pyrethrum and horticultural yields.

The fast progressing construction sector pushes the Rwandan industrial sector, which is increasing at a proportion of around 15% per year. Others key providers to the rwandan industrial sector are mining, cement, agro-processing, small-scale beverages, soap, plastic goods, agro-processing, furniture, shoes, textiles and cigarettes.

The electricity supply of Rwanda is composed of domestic generation and the imported electricity from neighbor countries and regional shared power plants. The source of energy used is from the following sources: hydropower plants, thermal power plants (Diesel and Heavy fuel generators), methane gas and solar energy. In order to solve the problem of power deficit known recently, the government rented thermal power plants as provisional solution.

Below is the chart showing the current Power Generation/Electricity Mix in Rwanda.

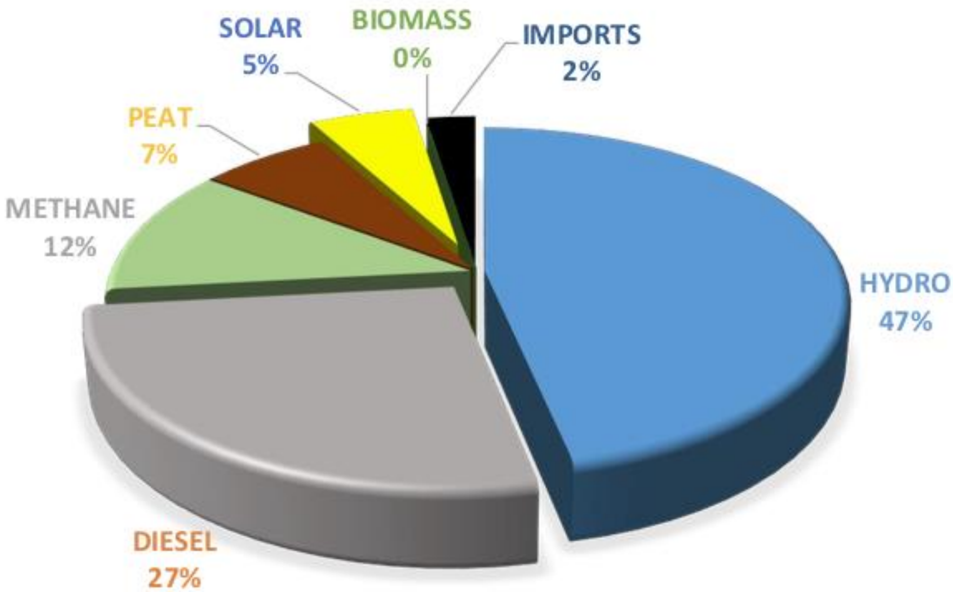

Figure 2.2: Rwandan energy mix source REG, 2018

The energy sector in Rwanda involves four main stakeholders: The Ministry of Infrastructure (MININFRA); the Ministry of Natural Resources (MINIRENA); the Rwanda Energy Group (REG); and the Rwanda Utilities Regulatory Agency (RURA). MININFRA is in charge of energy policy and strategy design as well as progress tracking and review, REG implements the energy policy and strategy, and RURA works as the regulator. MINIRENA has a mandate to ensure that environmental concerns are addressed in all new energy projects.

2.2.2. Energy resources

2.2.2.1. Biomass

In Rwanda, biomass is used in the form of firewood, charcoal, agriculture residues and biogas mostly for cooking purposes. In 2009, the annual quantity of biomass demand in the country was probable to be about 4,197,000 tons; nevertheless, the sustainable quantity of woody biomass that could have been collected in the same year was estimated to be about 3,327,000 tons (Drigo et al. 2013). To eradicate the biomass supply shortages and reach a sustainable equilibrium between the supply and demand by 2020, concerned parties are suggested to strengthen the distribution of Improved Cook Stoves (ICSs), encourage to plant more trees in farmlands, improve the management of existing forests, promote efficiency in charcoal making and plant trees on the areas with slope greater than 55% (The World Bank, 2012).

In the endeavor to decrease the weight on the woods stocks while improving health of biomass clients in the country, various activities have been attempted. These for the most part incorporate the scattering of ICSs. By and large a family with conventional stove needs about 1.6 tons of firewood every year to meet its cooking needs (The World Bank, 2012) while a family unit utilizing ICSs requires 23% less wood fuel.

Table 2.1: Annual consumption of firewood and charcoal per household and per capita (The World Bank, 2012)

Wood fuel type	Stove type	Consumption per household (kg/year)	Consumption per capita (kg/capita/year)
Fuel wood	Traditional/ three stones	1,642	355
	Improved	1,263	273
	Average	1,453	314
Charcoal	Traditional	700	152
	Improved	538	117
	Average	619	134

This shows how more utilization of ICSs can extensively add to diminish the current pressure any doubt on the nation's woodlands. Rwanda is one of African nations with a high entrance of ICSs (The World Bank, 2012) where the infiltration level achieves half (MININFRA, 2013). In any case, an investigation led via Care International uncovered that over 41.2% of family units that claim ICSs never use them (Munyehirwe, 2008). In this manner, more mindfulness battles with respect to the utilization of ICSs would be required so as to lessen the measure of biomass is important.

2.2.2.2. Hydropower

Hydroelectric power has played an important role in the socioeconomic development of Rwanda for decades since the 1950s. By the end of 2012, the estimated hydropower potential was 313 MW of which 64.5 MW, equivalent to 20% of the total potential, was in operation (AfDB, 2013). This potential includes both the internal or domestic and regional hydropower potentials. By generation technology mix of 221.1 MW, 45.17% is from hydropower generation, followed by diesel with 26.76%, Methane gas makes up to 13.89%, Peat with 6.94, % Solar energy has 5.9% and 1.62% imported from DRC and Uganda.

Rwanda is increasing its power capacity by exploiting both national and regional hydropower resources. **Ruzizi III** has a total capacity of 147MW out of which the Rwandese share represents 49 MW and **Rusumo** are developed as regional initiatives is a run-off river scheme set to generate 81MW to be equally shared between the three partner countries, while the GoR is currently investigating the feasibility of **Nyabarongo II with 37,5 MW.**

2.2.2.3. Solar energy

Due to its location, Rwanda is one of the countries that are enormous amounts of solar resources that can support other indigenous domestic resources to overcome the persisting energy supply challenges in the country. Solar energy in Rwanda varies according to the country's topography and increases from the west towards the east. In the western and northern parts of the country, the average annual solar radiation is estimated to be 3.5 kWh/m^2/day whereas in the central, southern and south−eastern regions the radiation can go up to 6.0 kWh/m^2/day (Hammami, 2010). Figure 3 shows the average spatial distribution of solar energy in Rwanda for the 1994−period.

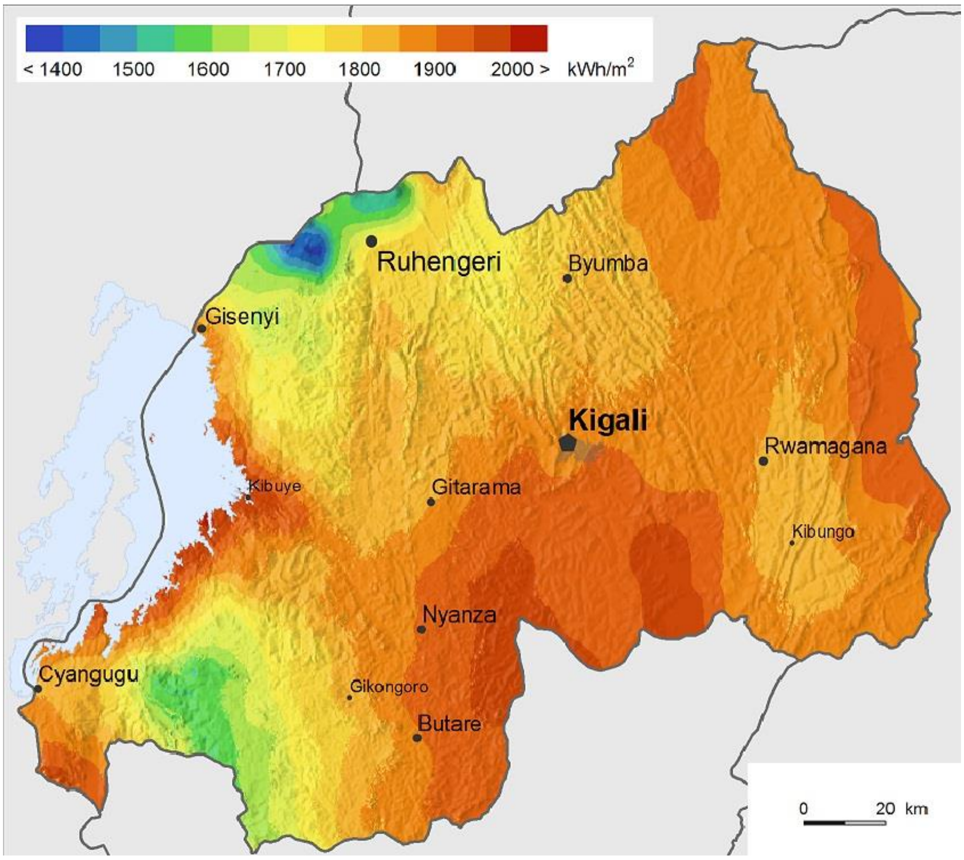

Figure 2. 3: Average annual sum of global horizontal irradiation in Rwanda for the 1994− 2010 period (GeoSUN Africa 2013)

Currently, Rwanda's total on-grid installed solar energy is 12.08 MW originating from 4 solar power plants namely Jali power plant generating 0.25MW, Rwamagana Gigawatt generating 8.5 MW and the Nasho Solar plant generating 3.3 MW.

2.2.2.4. Geothermal

A potential of 170 to 320 MW was estimated by Chevron (2006) and later to about 700 MW by Onacha (2010). However, from the two exploratory wells drilled in Kalisimbi to confirm the potential, no conclusions were made as the drilled wells did not confirm any existence of an underground hot water reservoir.

2.2.2.5. Methane Gas

It is estimated that, from methane reserves, 700 MW of electricity can be produced for a period of 55 years (REG,2015). It is important to recall that this resource is equally shared between Rwanda and the DRC, therefore each country can develop unilaterally up to one half of the estimated potential. By the end of 2014, a 4.5 MW pilot CH_4 based power plant was connected to the national electricity grid but delivers only 1.5 MW. In the same year different methane−to−power projects were under different development phases of which the most advanced was the Kivuwatt's 25 MW phase I which was under construction (REG, 2015).

2.2.2.6. Peat

Rwanda possesses a considerable amount of peat resources distributed across the country. A study on peat deposits in the country estimated a potential of about 2,650 m^3 equivalent to 155 million tons of dry peat (GTZ/MARGE, 2008). The main regions where peat reserves are found are Akanyaru (Western Province), Nyabarongo (Southern and Western Provinces) and Rugezi (in Northern Province) with respectively 69, 40 and 32 million tons of equivalent dry peat reserves (GTZ/MARGE, 2008)

Since 2010, the Government started development of a pilot 15MW peat power plant in Gishoma, Rusizi District, to reduce electricity deficit which the country was facing and to coincide with a significant growth of electricity demand observed in the region as a result of the expansion of the local cement factory and country development. As it was the first of its kind in Rwanda and in Africa in general, the plant was constructed as a pilot power plant and commissioned in 2016 to demonstrate the possibility of generating electricity from peat energy available in the region. Currently the power plant is working and successfully connected to the grid.

Figure 2. 4 :Gishoma fired peat power plant

Hakan Project of YUMN Ltd is developing an 80 MW peat fired power plant in South Akanyaru prospect in Gisagara District and the project is being developed as Public Private Partnership (PPP).

2.2.3. Demand forecast

An econometric assessment and forecast of annual consumption growth rates based on the available data on residential consumer consumption levels and electrical appliance use provided an estimate of 9.8% for the years 2016-2040. Bearing the uncertainties associated with demand forecasting and the different results presented by these studies, it was decided that an annual demand growth rate of 10% be used for Rwanda’s generation expansion scenario development and expansion planning. Figure 6 illustrates the forecasted 10% energy and peak demand growth.

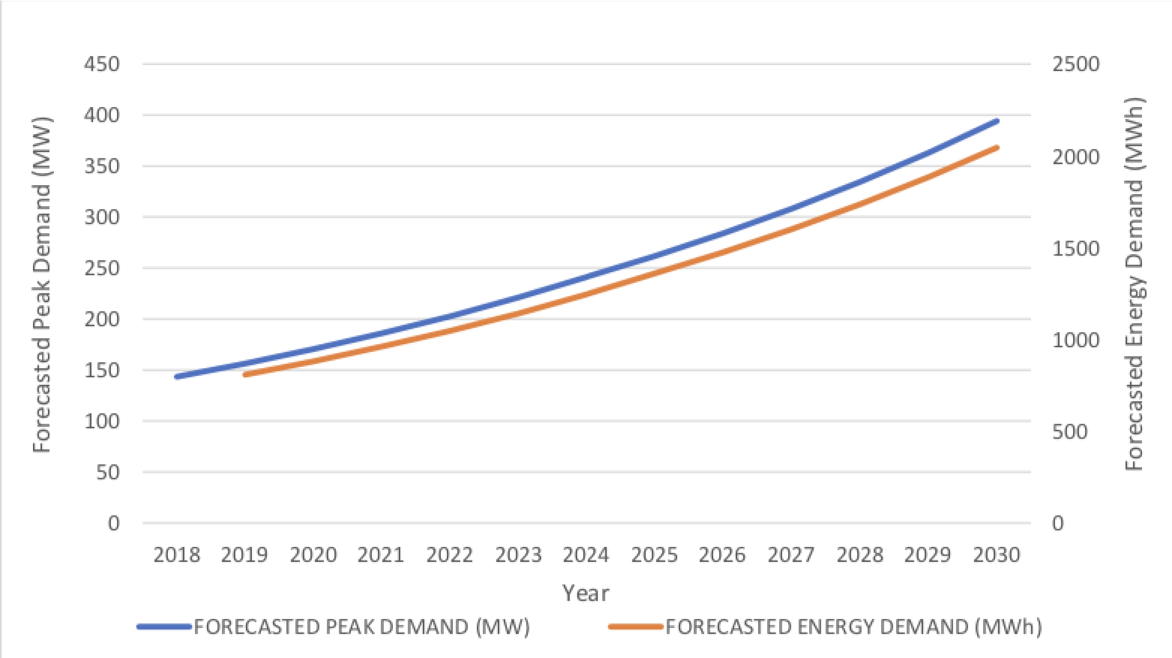

Figure 2. 5: Demand energy forecasting source (REG,2018)

2.3. Energy efficiency in Rwanda

A small number of energy efficiency programs have been continued or undertaken since 2007. These include:

- **Compact Fluorescent Lights (CFL)**: Supported by Government subsidy, REG distributed 800,000 CFLs in place of incandescent light bulbs between 2007 and 2014. To further support this initiative, an exemption of VAT on energy saving lamps was introduced in 2013. Benefits of this included a reduction in annual energy demand of 54 GWh and $11 million in savings for consumers.
- **'SolaRwanda' Solar Water Heaters (SWH):** A major ongoing initiative is the SolaRwanda Solar Water Heater Program, which promotes the use of solar water heaters, with the aim of reducing the use of electricity from the grid for water heating. The program was initiated in 2009 with the support of development partners and was formally launched in March 2012 with a pilot phase of 100 SWHs. Loans and grants are used to subsidise the cost of purchasing a SWH. Implementation commenced in April 2013 and a total of 2,256 SWHs have been installed.
- **Street Lighting**: A pilot project was implemented by the City of Kigali to replace high-pressure sodium (HPS) lamps with LEDs in street lights. This led to a 60% reduction of

power consumption from the baseline level. The financial savings or payback of the program will be analysed to inform future initiatives.

- **Loss Reduction**: REG is currently improving efficiency in two key areas. First, a program is in place to reduce network losses, which are currently 22%. Technical losses require additional generation to be undertaken, with negative environmental and financial impacts. Commercial losses reduce REG's revenues, reducing its ability to invest. The network is being expanded and strengthened. Significant investment is being made to upgrade the network around Kigali, which serves over half of Rwanda's demand. Improving the reliability and performance of the network will reduce the use of expensive, polluting diesel generators.

2.4. Energy efficiency policy framework

MININFRA developed an Energy Efficiency Strategy and Law to serve as underlying implementation framework to support a series of new regulations by RURA, RHA, and other agencies that can mandate energy efficiency measures in public institutions, households, and commercial businesses. MININFRA will be responsible for integrating the promotion of energy smart building technologies into monitoring and implementation of new government asset management policy. Together with RHA, it is also responsible for introducing energy smart and energy-efficient technologies and practices into Rwandan building codes.

RURA is already developing a solar water heater regulation. Considering building codes specifically: EE measures will be implemented in the form of improved building design and use of building materials that increase EE over the entire lifetime of facilities help to reduce lighting, mechanical ventilation and air conditioning energy consumption. Mandatory installation of solar water heaters for all large water consumers (e.g., hotels, integrated developments) will take effect, in parallel to extending subsidy to end-users to incentivize switching.

In addition, a training program on how to comply with the new EE building code should be established for architects, engineers and builders. Fostering green building through climate oriented urban planning principles and green architecture will have a strong long-term impact on reducing the need for electricity, and to reach this orientation of house and settlement should follow urban planning. Pilot efforts to promote energy smart building codes, particularly for green field construction projects, are being promoted in the six secondary cities of Huye, Nyagatare, Rusizi, Musanze, Rubavu and Muhanga, in conjunction with the National Urbanization and Rural Settlement Sector Strategy.

Table 2. 2: Energy Efficiency Implementation mainstream approach

Strategic Action	2013/14	2014/15	2015/16	2016/17	2017/18	Responsible Institution
Grid Loss Reduction Plan	Final report	Raising funds for implementation	Implement Phase I	Implement Phase II		REG
Establish Dedicated EE/DSM Unit		Develop staffing and business plan and establish EE/ DSM Unit Conduct detailed energy end-use surveys	-Undertake demand surveys -Behavioural change campaigns, investigate bulk procurement and distribution of CFLs, assess viability of incentives (retrofit subsidies)		Project Expansion subject to savings made. Provide TA.	REG & MININFRA
Industry Energy Audits		Develop strategy, business model for EE facility	Develop performance benchmarks	Develop and adopt minimum energy performance standards		MININFRA with RSB
Green procurement		Develop new guidelines	Approval by RPPA and legislation		Pilot and mainstream	RPPA & REMA
EAC–Wide Standards and Labelling	EAC Scheme	Standards Development; Raise Funds for Implementation		Pilot implementation of new standards		RSB
EE Strategy and Law		Develop Strategy. Develop and submit Energy Efficiency Law for approval			Streamline	MININFRA
Buildings	Adopt new SWH regulations with two-year phased compliance timeline			Close monitoring, evaluate as needed		RHA, RURA and MININFRA

2.6. Urbanization in Rwanda

Like many African countries, the historical traditional settlement pattern in Rwanda was homesteads in the countryside surrounded by agricultural fields. Traditional rulers regularly moved their courts from region to region, preventing an anchored catalyst for urban growth. Although there were regular market days, they did not provide the impetus to grow into permanent settlements.

At independence in 1962, Kigali was established as the capital, attracting investment and infrastructure development. There was an influx of people from the rural areas to feed the growing labor needs, which created a housing gap. Although colonial policies regarding urban planning, such as plot size, were applied, less than 10 per cent of housing needs were fulfilled (MININFRA, 2009). As a result, rural migrants tended to settle in inappropriate areas, such as flood plains or steep hillsides. These areas were characterized by overcrowding, poor sanitation and inadequate housing.

2.6.1. Contemporary urban growth

Although Rwanda is among the least urbanized countries in the world, it is also one of the fastest urbanizing ones, as shown by a comparison with Eastern Africa (Figure 7).

In 1950, Rwanda was the 6th least urbanized country in the world, at 2.1 per cent, and in 1990, it was the word's least urbanized country at 5.4 per cent urbanization. Today, urban growth in Rwanda is quite strong. Between 1990 and 2014, the country had the fastest urban population growth worldwide to 30 per cent of total population in 2032, equal to almost a doubling of the urban population in the next 20 years: 1.7 million in 2012 to 4.4 million in 2020 and 4.9 million in 2032, according to the medium-growth scenario. The Government of Rwanda's goal is to promote urban growth so that the proportion of those living in towns and cities will increase from 10 per cent in 2000 to 35 per cent in 2024 (RoR, 2012), which requires a more rapid urbanization process than is occurring naturally.

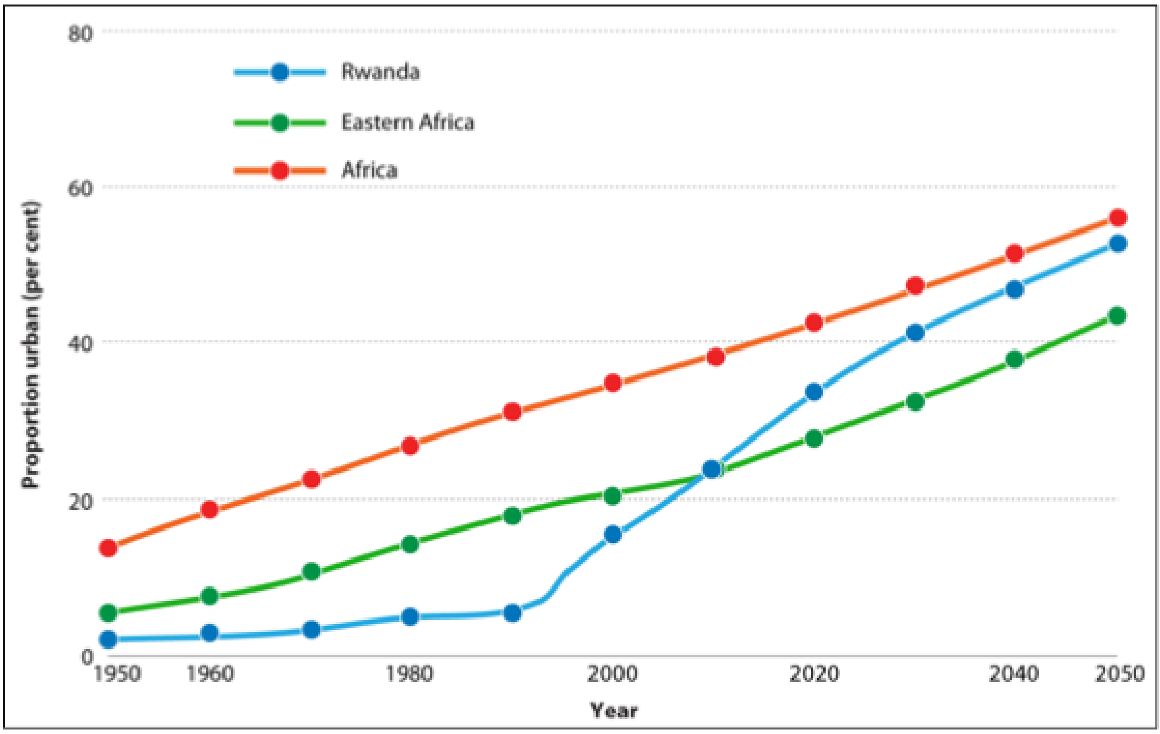

Figure2. 6: Rwanda's urban population growth in the context of Eastern Africa and Africa Source: (UNDESA, 2015)

To reach middle income status at 9 per cent a year while the rural population grew at only 1 per cent a year. This translates to an average annual urbanization rate of 6.8 per cent (UNDESA, 2015). Between 2014 and 2050, the pace will decline as Rwanda's annual rate of urbanization will fall to 1.8 per cent, making it the 7th fastest urbanizing country in the world. National data indicate that Rwanda has one of the highest annual urban growth rates worldwide — estimated at 4.5 per cent, which far exceeds the worldwide average of 1.8 per cent (Byaruhanga, 2017).

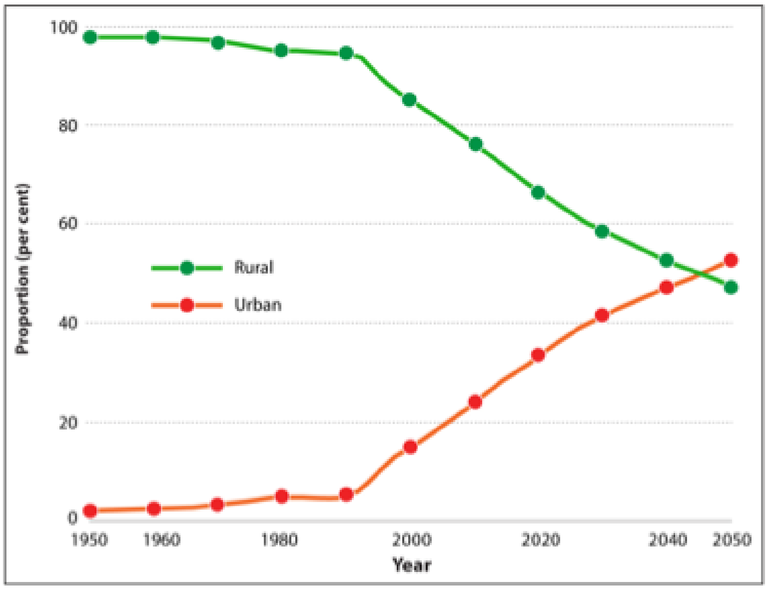

Figure 2. 7: Trend in the total population living in urban and rural areas in Rwanda, 1950 to 2050 Source: (UNDESA, 2014)

Figure 2.7 shows the dramatic trend in the absolute number of Rwandans living in urban and rural areas. Figure 2. 8 shows the trend in the relative proportions of the population living in urban and rural areas, from 1950 with projections to 2050.

Projections indicate that the urban population is expected to increase from 16.5 per cent in 2012 stipulated in its Vision 2020, the government calculates that this growth will require the generation of 1.8 million new off-farm jobs by 2020, recognizing that such jobs can only be created in urban areas. The 7-year Government Programme National Strategy for Transformation 2017–2024 highlights the potential for urban growth to bring economic development: "Urbanization needs to be accelerated for its transformational potential and its association with higher productivity, and higher income opportunities. With 70 per cent of the workforce still in agriculture, the potential for productivity gains from structural transformation, urbanization and industrialization is significant" (RoR, 2017).

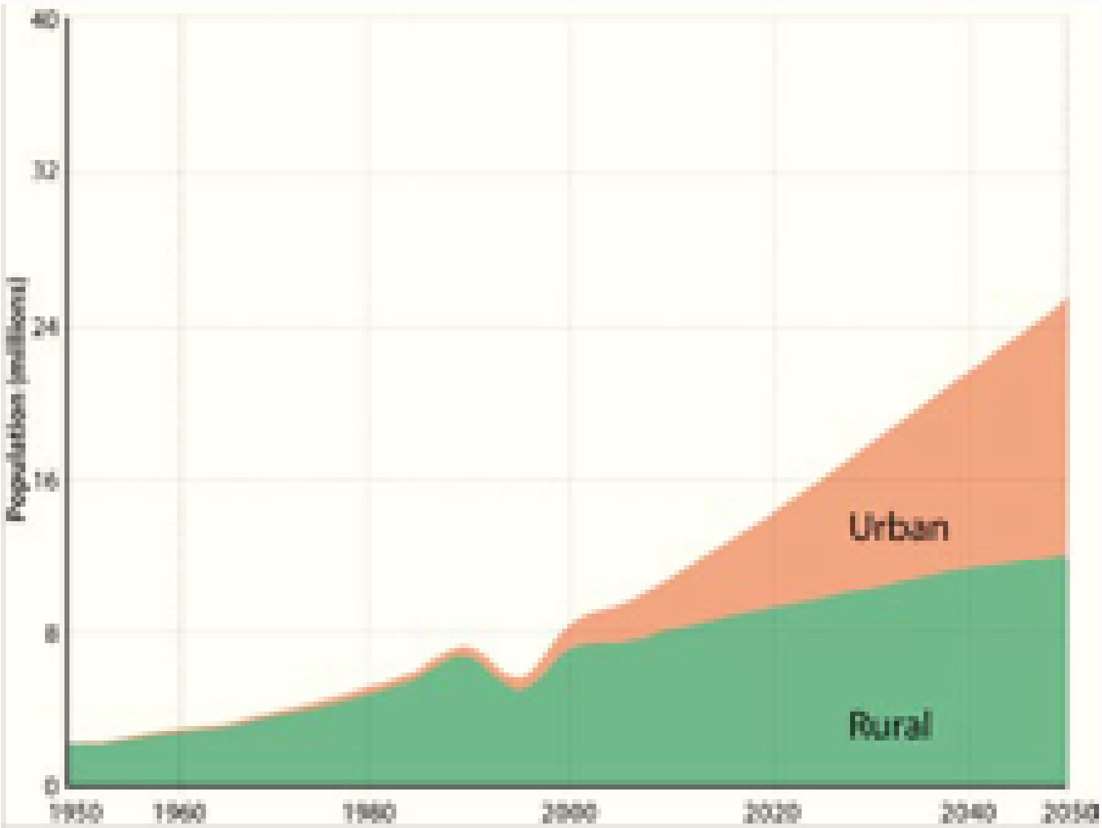

Figure 2. 8: Trend in the proportion of people living in urban and rural areas in Rwanda, 1950 to 2050 Source: (UNDESA, 2014)

At the same time, however, huge investments are needed to provide the infrastructure to accommodate some 2.7 million more urban dwellers (MININFRA, 2015); (NISR, 2014a). It also requires close management so that this growth does not occur at the expense of the environment and the support that ecosystem goods and services provide as the foundation for sustainable urban development. Providing the urban infrastructure for the growing urban population in a way that is environmentally sustainable is a challenge given Rwanda's hilly topography, the occurrence of heavy rains and the expected increase in precipitation with climate change.

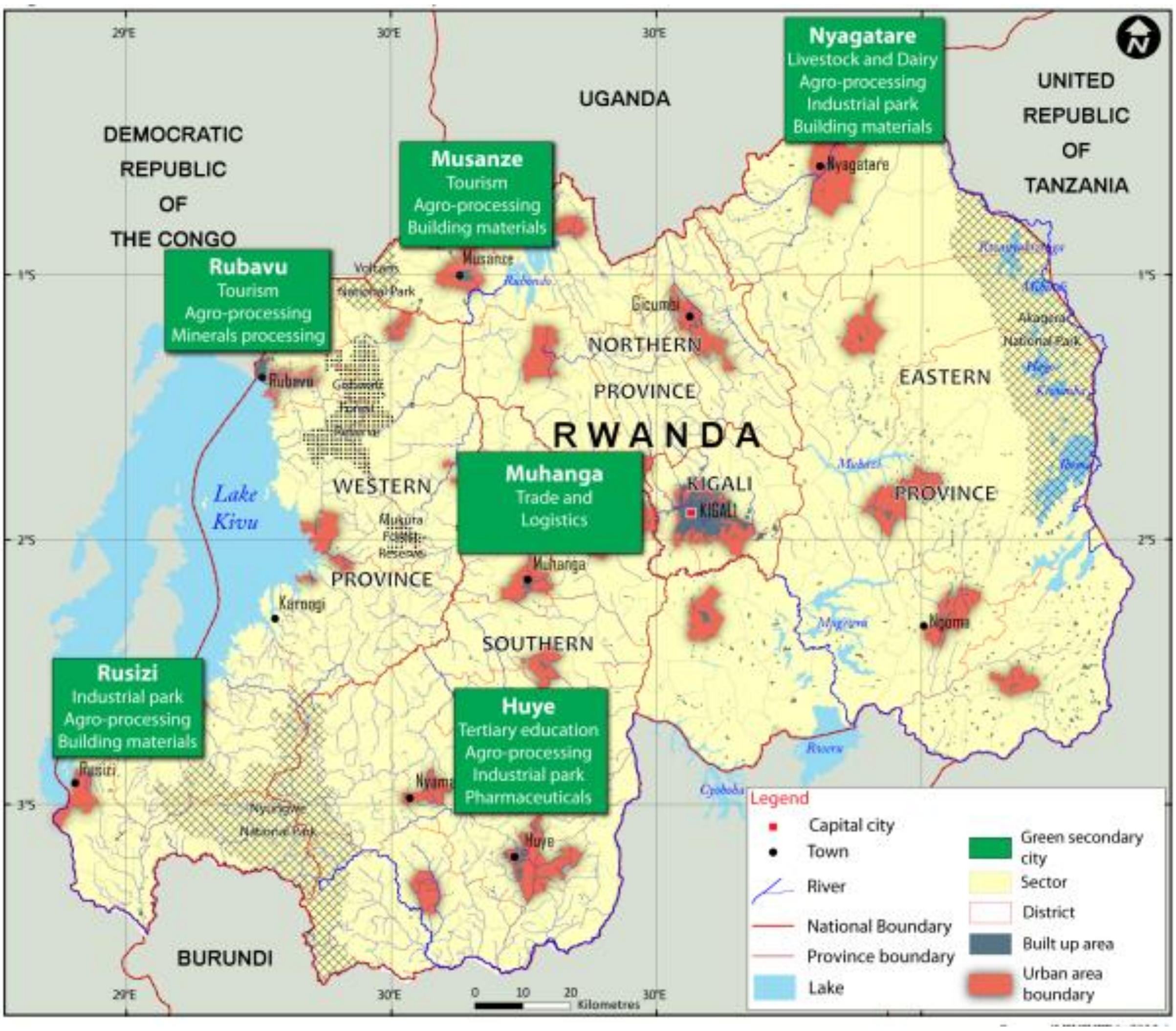

Figure 2. 9: Location of the six secondary cities

2.6.2. The urban population in secondary cities

According to the last census, the urban population in Rwanda is 1,737,684. Kigali is the largest city, with 75.9 per cent of its citizens living in the urbanized parts and where almost half of the country's urban population resides. The Western Province has 12.2 per cent of people living in urban areas, Northern Province has 9.3 per cent, Southern province 8.9 per cent and 7.2 per cent in the Eastern Province (NISR, 2012).

Rwanda is divided into 30 districts. The three districts of Kigali dominate in terms of urban population. Seven districts have urban populations lower than 10,000 and another ten have urban populations over 20,000. Rwanda's second largest city, Rubavu, has a population that is 17.3 per cent smaller than that of Kigali and a smaller urban population than any of the three districts that make up Kigali City.

Table2. 3: Key population indicators for the secondary cities source (GGGI, 2014)

City	District Population	Urban Population	% of District that is Urban	Population Growth Rate % (Medium Projection)	Urban Population Current Growth Rate %	Urban Poverty Rate %	% Living in Unplanned Areas
Huye	328,398	52,768	16.1	4	1.9	21.5	14.7
Muhanga	319,141	50,608	15.9	3	2.6	19.8	13.4
Musanze	368,227	102,082	27.7	4	3.1	28.6	36.6
Nyagatare	465,855	47,480	10.2	7	9	37.1	n.a.
Rubavu	403,662	149,209	37.0	6	5.4	35.5	8.7
Rusizi	400,858	63,258	15.8	5	2.4	20.1	4.3

The secondary cities of Huye, Muhanga, Musanze, Nyagatare, Rubavu and Rusizi (Figure2. 9) all have fairly small urban populations and together account for about a quarter of the country's urban population. They are all part of very rural districts in which subsistence agriculture is the main economic activity. Although opportunities in Rwanda's secondary cities are attracting people from other areas, only Nyagatare and Rubavu Districts currently have population growth rates higher than the national average. Population density, however, is higher than the national average in all but one (Nyagatare) of the six cities (GGGI, 2014).

2.6.3. Economic aspect in urbanization

Urbanization has long been linked to economic development and industrialization, with GDP growth thought to drive the development of urban centres. For instance, some estimates indicate that every 1 per cent increase in GDP results in a 0.9 per cent increase in urbanization (Hofmann & Wan, 2013). However, this must be viewed in the Rwandan context, given the level of economic development and the institutional framework, among other factors particular to Rwanda.

Table 2. 4: Estimated share of GDP of secondary cities theo

City	Estimated share of urban GDP (%)	Estimated share of total GDP (%)	Estimated GDP/capita ($)
Huye	2.4	0.7	928
Muhanga	2.3	0.6	924
Musanze	5.3	1.5	1,063
Nyagatare	2.1	0.6	920
Rubavu	8.0	2.3	1,055
Rusizi	2.9	0.8	936

The Global Green Growth Institute infers that in 2012, income generated in Rwanda's urban areas was just over $2 billion out of a national total of $7.22 billion, with only 16.5 per cent of the population residing in Rwanda's urban areas at the time and 33 per cent of consumption concentrated in those areas. It estimates that Kigali accounted for nearly 61 per cent of the urban GDP (GGGI, 2015). Table 1.4 shows the share of economic activity concentrated in each of Rwanda's secondary cities, revealing that the next largest cities of Rubavu and Musanze accounted for 8 and 5.3 per cent of urban GDP. Rwanda's National Strategy for Transformation (NST 1) 2017 – 2024 urges that urbanization be "accelerated for its transformational potential and its association with higher productivity, and higher income opportunities" (RoR, 2017).

2.6.4. Access to electricity and other energy sources

All cities are connected to the national electricity grid. As the National Energy Strategy is implemented, this will enable greater electricity access and local generation to be fed into the grid (GGGI, 2015).

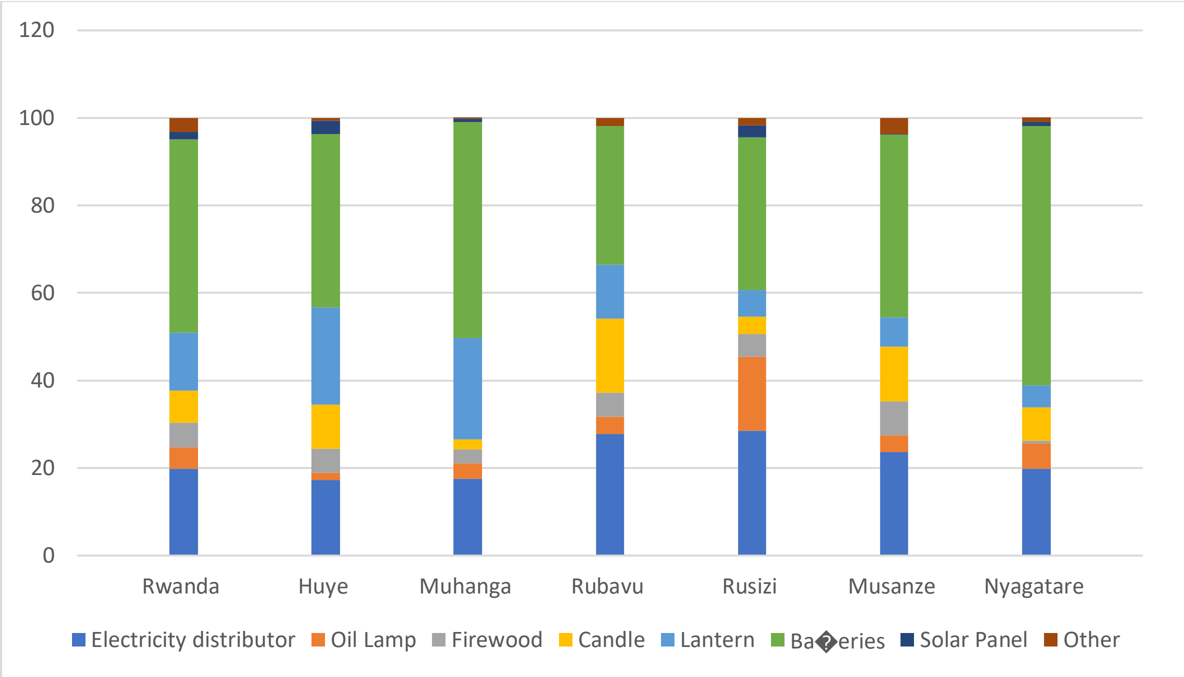

Figure 2. 10: Primary fuel used for lighting, by six secondary cities districts with secondary city (%) (from EICV4) Source: (NISR ,2016)

According to the Demographic and Health Survey of 2014/15, the electrification gap between rural and urban areas is substantial, with only 12.4 per cent of rural areas being electrified compared to 72.9 per cent of urban areas. Despite the relatively high urban electrification rate, only 0.3 per cent of households use it for cooking (NISR, 2015). The majority (65.5 per cent) cook with charcoal and 26.1 per cent use wood. Liquefied Petroleum Gas (LPG) is used by only 1.5 per cent of urban households (NISR, 2015). The proportion of urban households using solid fuels for cooking is 94.6 per cent, showing that access to modern fuels remain extremely low (NISR, 2015).

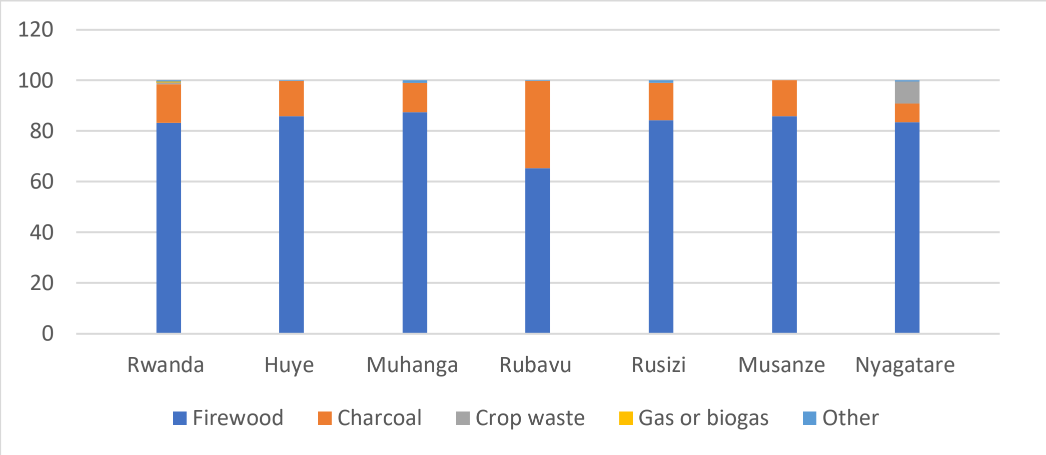

Figure 2. 11: Primary fuel used for cooking in secondary cities (%) (from EICV4) Source: (NISR ,2016)

Figure 11 shows the energy sources used for lighting in urban areas, revealing that kerosene lamps are the most common usage. Figure 12 shows that charcoal is by far the most common source of energy for cooking, while firewood is the dominant source of fuel for cooking in all the secondary cities.

Table 2. 5: Green technologies – actual and potential

City	Hydro/ micro-hydro power	Lake Kivu methane	Geothermal	Sustainable construction material production	Solar water heaters	Biogas for cooking	Energy saving lamps	Energy – saving wood –burning stoves
Huye	√√√			√	√√	√√	√√	√√√
Muhanga	√√√			√	√√	√√	√√	√√√
Musanze	√		√	√√√	√√	√√	√√	√√√
Nyagatare				√	√√	√√	√√	√√√
Rubavu	√√	√√	√	√	√√	√√	√√	√√√
Rusizi	√√√			√	√√	√√	√√	√√√

Notes:
√: the technology has considerable potential to be developed in the secondary city

√√: the technology is being trialed but is not yet widely established and rolled out

√√√: the technology is established (though further development is possible). Source: (GGGI, 2015a)

The use of firewood and charcoal causes deforestation unless supported by sustainable forestry. To reduce the consumption of firewood for cooking purposes, the Government of Rwanda has been promoting the installation of energy-saving cooking stoves (rondereza). There have been a number of pilot projects for this technology in Kigali as well as in all secondary cities. There are numerous problems associated with their introduction, however, as highlighted further on in this report. Nationally, about 20 percent of households in urban areas use energy-saving cooking stoves, compared to around 38 per cent in rural areas (GGGI, 2015a).

2.7. Energy efficiency benefits

Energy is fundamentally linked with social and economic development, so it is not hard to imagine that energy efficiency could be a means to realizing policy goals beyond the energy sector. Some outcomes may be indirect, or be the product of a chain of actions which are difficult to attribute to energy efficiency. Energy efficiency measures can nevertheless be seen to have impacts on various areas in the economy, often in different areas at the same time, and a direct impact in one area of the economy may have flown effects in other.

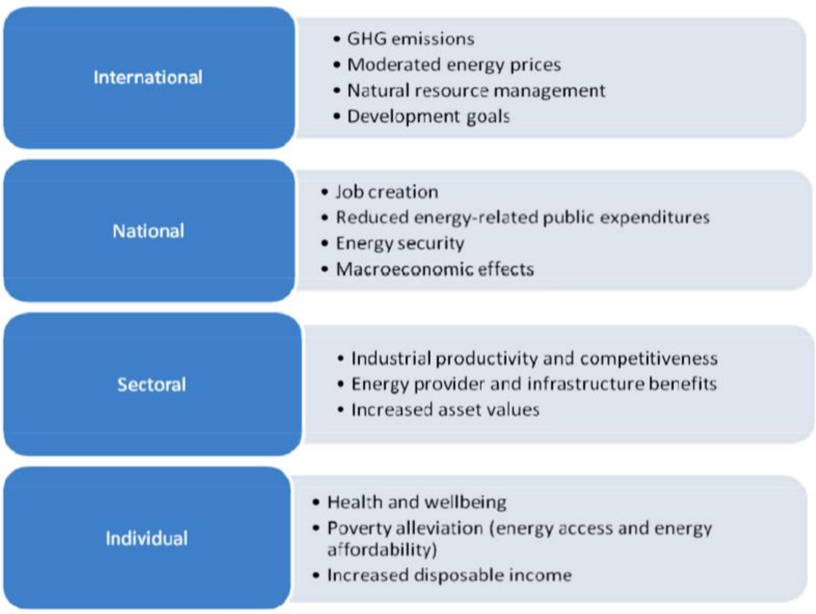

Figure 2. 12: Energy benefits source (IEA, 2014)

2.7.1. Individual level (individuals, households, enterprises)

- **Health and well-being impacts**: This mainly relates to the public health improvements observed as a result of improved heating and cooling of buildings and air quality from more efficient transport and power generation and less demand for both.
- **Poverty alleviation: Energy affordability and access:** As energy demand and bills are reduced for the poor, these households have the ability to acquire more and better energy services, as well as free up income to spend on satisfying other critical needs. In addition, as utilities (notably in developing countries) improve their SupplySide efficiency, they can provide more electricity to more households, thereby supporting increased access initiatives which is often an important stated objective of SupplySide energy efficiency activities in developing countries.
- **Increased disposable income**: Across all income levels, when energy efficiency improves, reduced energy bills provide increased disposable income for households, individuals, and enterprises. The effect of increased spending and investment can in turn result in positive macroeconomic effects described below.

2.7.2. Sectoral level (economic sectors: industrial, transport, residential, commercial)

- **Industrial productivity and competitiveness**: Benefits for industrial firms from improvements in energy efficiency improvements include reductions in resource use and pollution, improved production and capacity utilization, and less operation and maintenance, which leads to improved productivity and competitiveness.
- **Energy provider and infrastructure benefits**: Improved energy efficiency can help energy providers provide better energy services for their customers, reducing operating costs and improving profit margins.
- **Increased asset values**: There is evidence that investors are willing to pay a rental and sales premium for property with better energy performance. Some values of this premium have been estimated for commercial property.

2.7.3. National level

- **Job creation**: Investment in energy efficiency and the increased disposable income can lead to direct and indirect job creation in energy and other sectors. This makes energy efficiency an important part of governments' green growth strategies.

- **Reduced energy related public expenditures:** The public budgetary position can be improved through lower expenditures on energy in the public sector (including by government agencies on energy consumption and state-owned utilities on fuel purchases). In countries where fuels are imported there is a related likely positive impact on currency reserves, and in energy exporting countries domestic energy efficiency can free up more fuels for export. In addition, for countries with energy consumption subsidies, reduced consumption means lowered government budgetary outlays to finance these subsidies.
- **Energy security:** Improvements in energy efficiency leading to reduced demand for energy can improve the security of energy systems across the four dimensions of risk: fuel availability (geological), accessibility (geopolitical), affordability (economic) and acceptability (environmental and social) (APERC, 2007; Kruyt *et al.*, 2009). The IEA's existing work on energy security underlines the contribution that energy efficiency improvement can make to energy security. While policy makers are alert to this connection, the multidimensional nature of energy security makes it difficult to quantify and few studies have attempted this on a comprehensive, economywide scale.
- **Macroeconomic effects**: Energy efficiency can have positive macroeconomic impacts, including increases in GDP, and the cumulative benefits of the abovementioned impacts of improved trade balance (for fuel importing countries), national competitiveness, and employment support. These are mainly indirect effects resulting from increased consumer spending and economywide investment in energy efficiency, as well as from lower energy expenditures.

2.7.4. International level

- **Reduced GHG emissions**: Greenhouse gas (GHG) emissions are reduced when energy efficiency improvements result in reduced demand for fossil fuel energy. Many climate change mitigation strategies put energy efficiency measures at their core as the most costeffective way to reduce greenhouse gas emissions.
- **Moderating energy prices**: If energy demand is reduced significantly across several markets, energy prices can be reduced, particularly relative to the impact of the counterfactual of increased energy demand. This can have implications on economic competitiveness of countries, and, for individuals across borders, improves the affordability of energy services and the availability of resources for other expenditures.

- **Natural resource management**: At an aggregated international level, less demand can reduce pressure on resources, with potential beneficial impacts on prices (at least for importing countries), as well as overall resource management. For example, in the context of peak oil and related supply constraints, energy efficiency can help to relieve pressure on a scarce resource. Similarly, expanding demand for oil etc., is pushing industry to increasingly challenging contexts for extraction (such as deep offshore and shale oil extraction), with related incremental investment costs and technological and environmental uncertainties.
- **Development goals**: Improved energy efficiency is important in achieving economic and social goals in developing countries, including improved access to energy services, eradicating poverty, improving environmental sustainability, and economic development. Advancing development in these countries in a sustainable way is a shared international goal with benefits for developing countries themselves and for developed countries as well.

2.8. Computer tools for energy planning

The impacts of energy efficiency policy have received a political push regarding to the sustainable development perspective (Goldemberg and Johansson, 2004; Metz et al., 2007). Policy evaluation research is commonly, though not exclusively, concerned with the simulation and modelling of the impacts of different policy instruments for increased energy efficiency. In past decades, we have seen an increased use of bottom-up energy models in policy- making to evaluate ex-ante the energy, economic, and environmental impacts of energy efficiency policy instruments. The use of engineering-economic based energy modelling tools for energy efficiency policy analysis has gained widespread recognition at all levels of policy-making in recent years.

Energy efficiency scenarios are developed in national and international contexts to explore and evaluate different policy designs and visions of how energy will or should be generated, distributed and used in the future. These scenarios are often developed using bottom-up modelling tools that, only to a limited extent, take into account decentralised decision-making frameworks, such as household decisions regarding energy-efficient technologies (Hourcade et al., 2006). However, the role of energy models and resulting outcomes is paramount because of their effect on policy and decision-making processes. Energy models and modelling studies have historically provided useful policy insights in aspects such as competition of demand-side energy technologies; end-use energy efficiency potentials; and fuel substitution and related atmospheric emissions, among others (e.g. Metz et al., 2007).

Uncertainties associated with energy models and scenarios can be distinguished between "data uncertainties", "modeling uncertainties" and "completeness uncertainties" (Functowicz & Ravetz, 1990). Data uncertainties are related with the quality or adequacy of the input data for the model. Uncertainties of the model arise from approximations of the formal representation of dependencies, or from a lacking understanding of the phenomena modeled. Finally, completeness uncertainties arise through omissions due to incomplete knowledge. The uncertainties of outputs with respect to its input (e.g. gross domestic product (GDP)) are assessed in sensitivity analyses, showing how robust model outputs are (DEA, et al., 2013).

However, policy and technology choices induce a dilemma in the choices of energy models. "Energy models can simulate sector specific future energy supply and demand including impacts on economic growth, employment or foreign trade. Every modeling approach abstracts to a certain degree from reality using facts, statistical average figures as well as assumptions. Energy models have specific advantages and limitations of which modellers, policy makers and users are often not sufficiently aware of the result" (Böhringer, C., 1998). A large number of modeling approaches are developed depending on their intended use (data analysis, forecasting, optimization, simulation, estimation of parameters), target groups (research communities, policy makers, utility companies), the information available (useful energy, energy demand data on final energy, sector wise energy demand), regional (national regional multinational) and conceptual framework (top-down, bottom-up)

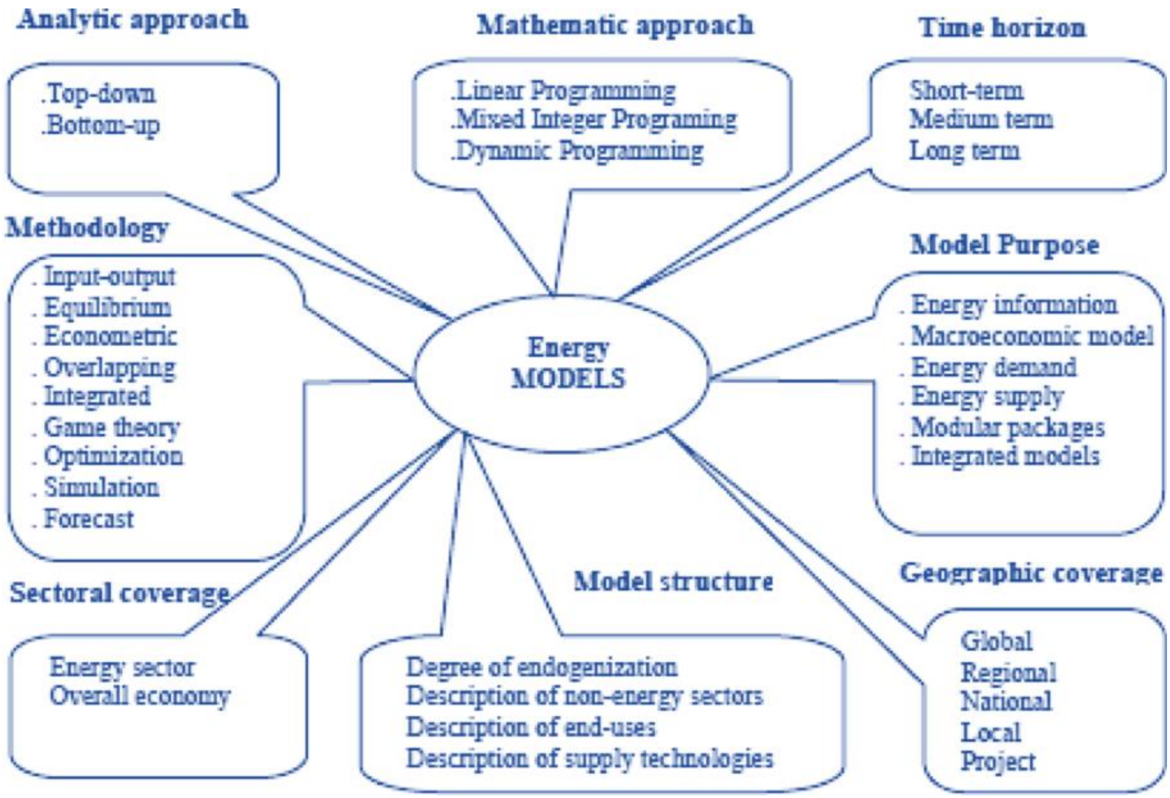

Figure 2. 13: Energy models approach

2.8.1. Energy Models approaches

Policy making in the energy sector is strongly influenced by models designed to forecast the effects of policies on energy demand, energy related pollution and economic output. The high capital intensity of the sectors are reasonable grounds for the application of simulation and optimization algorithms. Internationally, the global warming concern has been stimulating the energy modellers to develop more sophisticated energy models and climate change assessment models.

Energy models represent a more or less simplified version of the real economy. At best they provide a good approximation of today's reality. Most of the energy models comprise the following main processing features:

- Principle: Simulation and optimization
- Approach: sectoral ("top-down") or technology-oriented ("bottom-up")
- Structure: point model (reduced to the consideration of production and demand without power restrictions) or extended model (including grid considerations)

- Period: long-term study (typical input variables: years of integral power generation or work) or short-term resource planning (use of existing or specified power plants typical input: load profile and power) (Pandey, 2002).

The purpose of using energy models in scenario analysis is the most commonly used parameter for model choice and relates to the different factors to organize large amounts of data, to provide framework for testing hypothesis and to reflect understandable form of complex systems (Heaps, 2011). The increasing energy demand and environmental concerns have led to the creation of a number of energy models which can be classified in two major categories (Rivers and Jacard, 2005).

The two major approaches for energy sector mitigation assessment models are:

Top-down models describe the energy system in aggregate relationships derived empirically from historical data.

- Important where GH mitigation activities will cause substantial changes to an economy
- Assume competitive equilibrium and optimizing behavior in consumers and producers
- Examine general impact of GHG mitigation on the economy
- Typically examine variables such as GDP, imports, exports, employment, public finances, etc.
- Can be used in conjunction with bottom-up approaches to help check consistency; such as energy sector investment requirements from bottom-up energy models used in macroeconomic assessment to iteratively check the GDP forecasts driving the energy model (UNFCCC, 2005).

Bottom-up models which determine the financially optimized (cheapest) way based on available technologies and processes. Bottom-up energy models use highly disaggregated data on specific technologies such as estimated cost of energy technologies. This would make it possible to produce detailed and fair energy use projections by type and sectors, typically to identify least-cost configurations (Wilson et al 1993). Bottom-up energy models are categorized as: optimization models, simulation Models and accounting Frameworks

Table 2. 6: Principal top-down models and bottom-up models (Source: Van Beeck, 1999)

Top-down	**Bottom-up**
Use an economic approach	*Use an engineering approach*
Cannot explicitly represents technologies	*Describe technologies in detail*
Use aggregated data for the predicting purposes	*Use disaggregated data for exploring purposes*
Most efficient technologies are given by the production frontier	*Efficient technologies can lie beyond the economic production frontier suggested by market behavior*
Reflect available technologies adopted by the market	*Reflect technical potential*
Based on observed market behavior	*Independent of observed market behavior*
Endogenize behavioral relationships	*Assess costs of technological options directly*

Both types of models (top-down and bottom-up) have specific advantages and limitations of which users of the results, modellers and policymakers need to be sufficiently aware. The choice of models tends to reflect a trade-off between model performance and expected output from model use on the one hand and availability of resource data on the other hand. One major advantage of top-down energy models is their application of feed-back loops to economic growth and employment. In contrast, bottom-up modeling approaches incorporate a high degree of technological detail, which enables them to present very detailed output of energy demand and supply technologies (Herbst, et al 2012). According to a Danish energy report (Danish Energy Agency 2013), the bottom-up model approach is missing out with broader macroeconomic developments, whereas top-down models lack detail of technological data. Table 7 presents an overview of energy models with their strengths and weaknesses in the application.

Table 2. 7: Overview of Energy Models (Source: Danish Energy Agency 2013)

Bottom-up			**Top-down**		**Hybrid**
	Accounting	**Optimization**	**Simple extrapolation**	**Computable general equilibrium**	**Hybrid**
Strengths	Ease-of-use and potentially small data need	Technological detail and least cost projections	Ease-of-use and potentially small data needs	Feed-back effects on macroeconomic variables	Technological detail and consistency with economic projections
Weaknesses	Linkages with broader macroeconomic developments missing		Lack of technological detail		Can be very resource-intensive
Examples	LEAP, MEDE & MAED	MARKAL/ TIMES, POLES MESSAGE and EFOM	Spreadsheet models	ENV-Linkages (OECD), SGM and CETA	WEM (IEA), NEMS, MARKAL-MACRO and IPAC

The International Energy Agency World Energy Model (WEM) hybrid type of model attempts to bridge the difference between bottom-up and top-down approaches like other hybrid models.

According to the theoretical approach, a further classification of energy models explains the basic methodological differences between bottom-up and top-down models (Heaps, 2002). Regarding the mathematical form, bottom-up energy models have been developed in the form of optimization models (e.g. MARKAL/TIMES), simulation (accounting) models (e.g. LEAP) and more recently multi-agent models "Most of the bottom-up models limit their cost and investment calculations to the conversion sector and cross cutting technologies in the final energy sectors" (Herbst, et al 2012).

Optimization models

Optimization energy models incorporate some optimizing behavior for economic decisions. The methodologies are used to optimize investment decisions endogenously. The models are often used by utility companies or municipalities to derive their optimal investment strategies and are used for analyzing the future energy system for national energy planning. The models require a relatively high level of mathematical knowledge. The use of optimization models is limited to discrete energy conversion technologies and typified energy uses as the information on investment and operating cost are needed for the optimization (Heaps 2002). "It is impossible for optimization models, for instance, to simulate the demand of the services and industrial sector due to their technological variety where cost information cannot be made available" (Herbst, et al 2012). In addition, optimization models neglect the fact that severe market imperfections and obstacles in many final energy sectors and the conversion sector are not simulated which leads to unrealistically low projections of energy demand. MARKAL (MARket ALlocation) and MESSAGE (Global energy systems model) are the most widely used optimization energy models (Herbst, et al 2012).

Simulation models

Simulation energy models allow users to simulate behavior of consumers and producers under various signals (policies, incomes, prices) to systematically analyze an assumed policy related development in each sector. The models allow the users to explore different scenarios and investigate technologically oriented measures. Accounting frameworks are considered to be a simple form of simulation models which aims to account for the physical and economic flows of the energy system (Heaps, 2002). The models set up an accounting balance for the flow of energy through an economy for a period of time. The iterative approach is used to find the market clearing demand and supply equilibrium. These types of models enable the modeller to explicitly specify outcomes. This type of model accounts for the outcomes of the assumed development. "This approach is commonly applied to project future energy demand of final energy sectors and the related emissions. Due to their simple structure, accounting frameworks

Multi-Agent Models

Multi-agent modeling is a simulation approach which considers market imperfections like asymmetric information, strategic behavior and other non-economic influences. "Multi-agent models are limited to applications of the energy converting technologies and a few applications on final energy sectors" (Herbst, et al, 2012,). Major obstacle of multi-agent models is the demand on additional empirical data.

CHAP III. MATERIALS AND METHODS

3.0. Introduction

This chapter, describes the area from which this study was conducted, materials used and the procedures taken to determine the sample size, data collection methods and analysis tools used to get the results.

3.1. Study Area

3.1.1. Geographic description.

Musanze is one of five districts that make up the Northern Province of Rwanda. Its northern border is shared with Uganda and the Democratic Republic of Congo (DRC). Burera district shares its eastern border while Gakenke and Nyabihu districts share the southern and western borders, respectively. The district comprises 15 sectors: Busogo, Cyuve Gacaca, Gashaki, Gataraga, Kimonyi, Kinigi, Muhoza, Muko, Musanze, Nkotsi, Nyange, Remera, Rwaza and Shingiro. These sectors are divided into 68 cells and 432 villages (Figure 15).

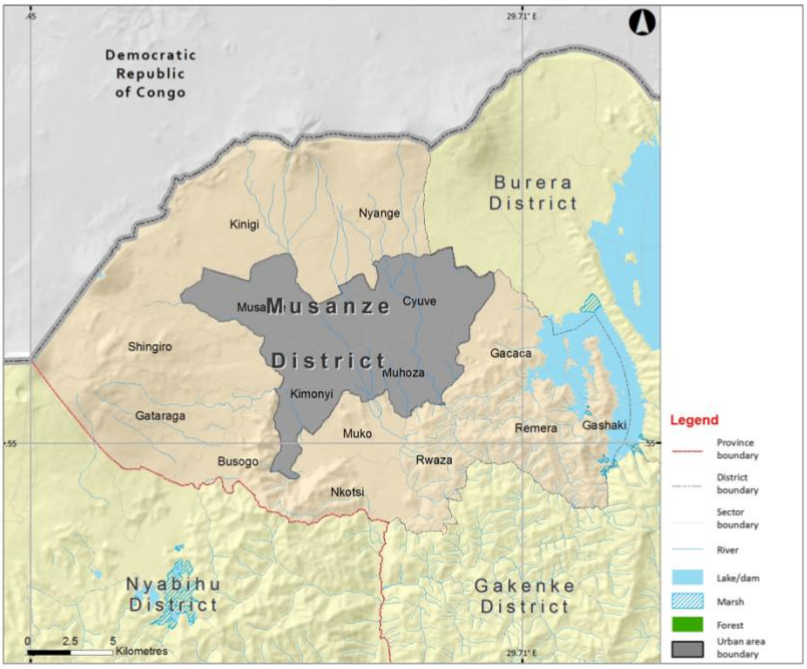

Figure 3. 14:Musanze Map

The area extent of the district is 530.4 km^2. Natural resources assets within the district include 60 km^2 of the Volcanoes National Park in the north and northeast and 28 km^2 of Lake Ruhondo in the southwest, making the district the country's tourism hub (RoR-MD, 2013)

There are two main parts to the topography of Musanze: the volcanic plains and the mountainous area; in the latter, altitudes range between 1,800 - 4,507 m. It is the most mountainous part of the country and contains five of the eight volcanoes of the Virunga chain: Karisimbi (4,507 m), Muhabura (4,127 m), Bisoke (3,711 m), Sabyinyo (3,574 m) and Gahinga (3,474 m) (MININFRA, 2016c). The mountain range covers about 30 per cent of the total land area of the district and includes the sectors of Cyuve, Gacaca, Gashaki, Muhoza, Nkotsi, Remera and Rwaza (MININFRA, 2016).

3.1.2. Population

The population in this district increased from 307,078 in 2002 to 368,563 in 2012, with a population density of 695 people per km^2. The average annual population growth rate is 1.8 per cent (RoR-MD, 2013a). Musanze district has the second highest population density and the second lowest population growth figures of the six secondary cities.

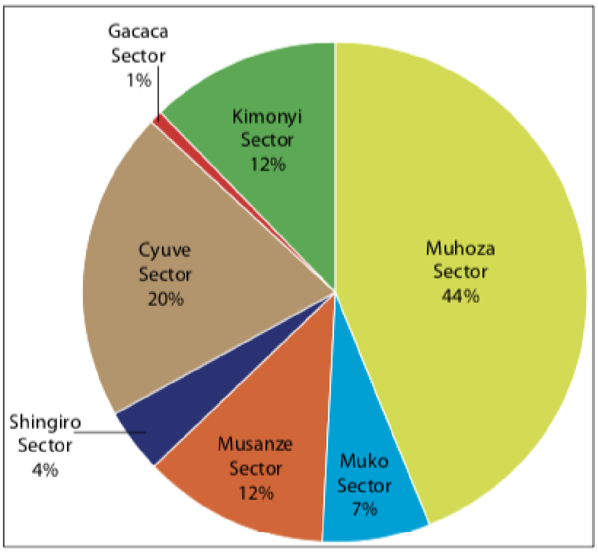

Figure 3. 15: Musanze city population distribution

The total urban population of Musanze City in 2012 was 99,387 and this contributed 1.2 per cent of the total urban population of the country and 32 per cent of the total district population. The annual growth rate of the city is 1.8 per cent. Musanze City covers 7 Sectors, 21 cells and 91 villages and has a total household population of 20,260 (MININFRA, 2016). The sectors' contribution to the total population is as follows: Muhoza: 43.6 per cent; Cyuve: 20.4; Musanze: 12.4; Kimonyi: 11.9; Muko: 6.5; Shingiro: 4.2; and Gacaca: 1.0 per cent (MININFRA, 2016)

3.1.3. The economy

Musanze city has the highest per capita income in Rwanda, higher even than Kigali. Livelihood opportunities and economic growth in Musanze are strongly linked with the environment and natural resources. The district serves as the tourist hub of Rwanda due to the presence of the rare Mountain gorillas, the Golden monkeys and the majestic mountains within the volcanic Virunga range.

Agriculture is another strong livelihood activity with 91 per cent of the population involved in farming. It employs 67 per cent of the workforce (GoR & GGGI, 2015). Other important contributors to the economy include Irish potatoes, construction materials, jewelry, handicrafts and essential oils from rose and geranium (GoR & GGGI, 2015). Total employment increased from 8,151 in 2011 to 9,853 in 2014 with 2 new large- size economic activities (MININFRA, 2016c). Retail trade is the most common economic activity at 61 per cent followed by manufacturing and accommodation and food service.

3.1.4. Energy

In 2013/2014, 23.6 per cent of households used electricity as the main energy source for lighting, an increase from 2010/2011 when it was only 14.5 per cent. The most commonly usedenergy source for lighting in 2013/2014 was batteries (41.7 per cent).

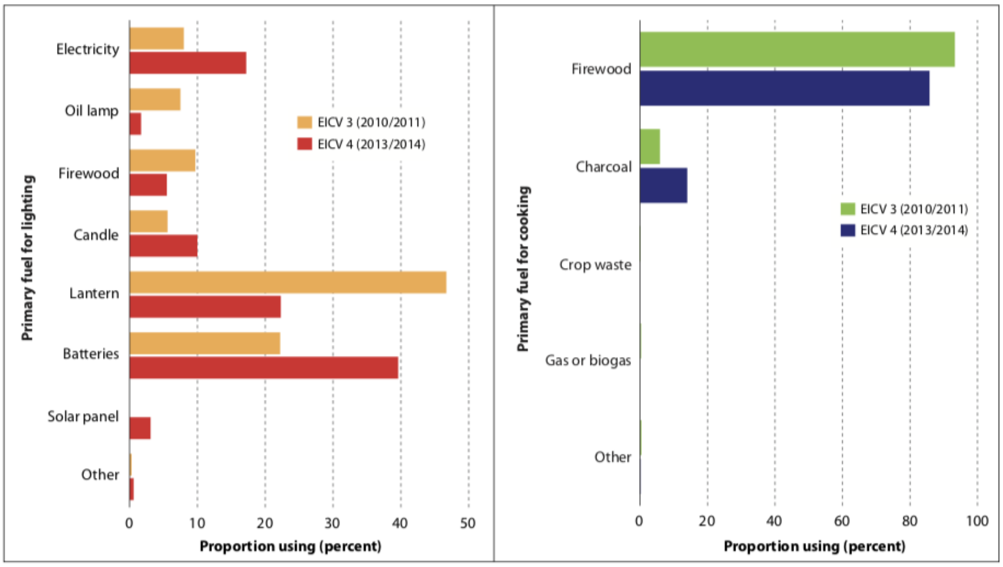

Figure 3. 16: Musanze energy demand source (NISR,2016)

Electricity is not used for cooking, with all households using some form of biomass (charcoal or firewood) (NISR, 2016). An increase in access to electricity has the potential to promote development and diversification of off-farm livelihood activities, improve delivery of services such as education, health and ICT at the local government level and reduce pressure on forest resources. It would also better serve the tourism industry in accommodating visitors in lodgings with modern services.

The main sources of energy for cooking used by private households vary by area of residence. In urban areas, households use more firewood (48.6%) and charcoal (48%) as shown on figure 18.

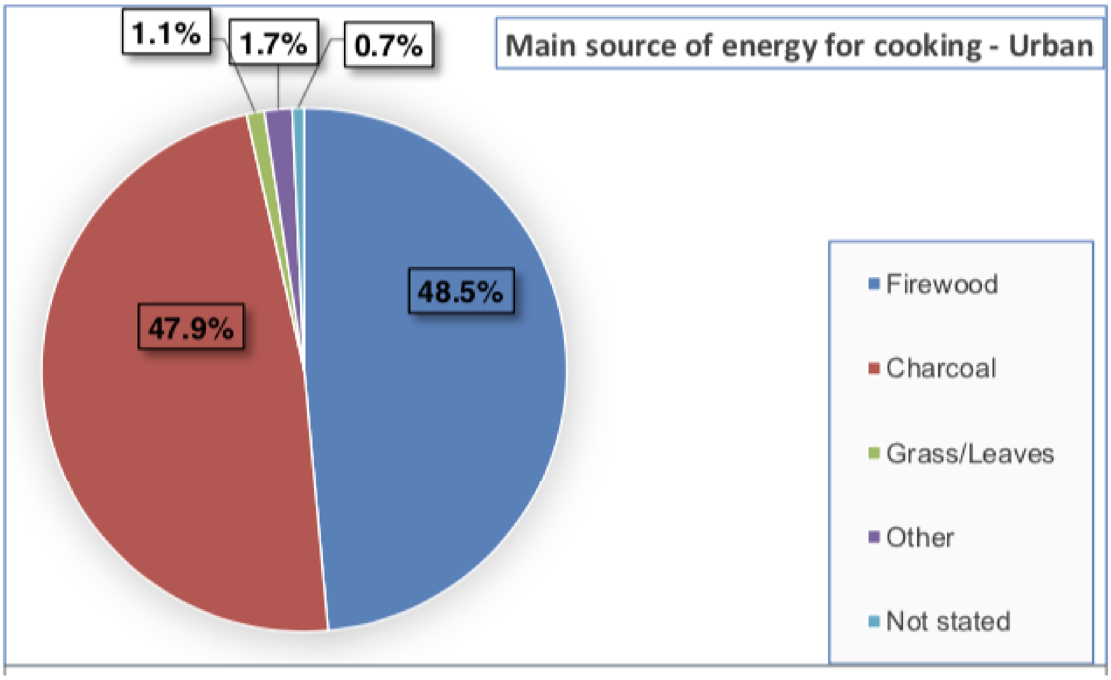

Figure 3 17: Distribution (%) of households of Musanze district by main source of energy for cooking source NISR, 2012

3.2. Research Design

The study involved the qualitative and quantitative data, collected using descriptive research design. This study described the dependent and independent variables, as well as the evaluation of the relationship between independent and dependent variables in terms of percentages. It involved also primary and secondary data. For modelling and analysis of a long-term residential energy demand projection for Musanze city the population, national economic growth, sectorial value and energy intensities are the key drivers for the base year modelling. In the LEAP model framework, scenarios are based on detailed data of the types of energy consumed by the residential sector using various fuel types. In this research, scenarios were created to develop long-term energy plans and to understand energy demand.

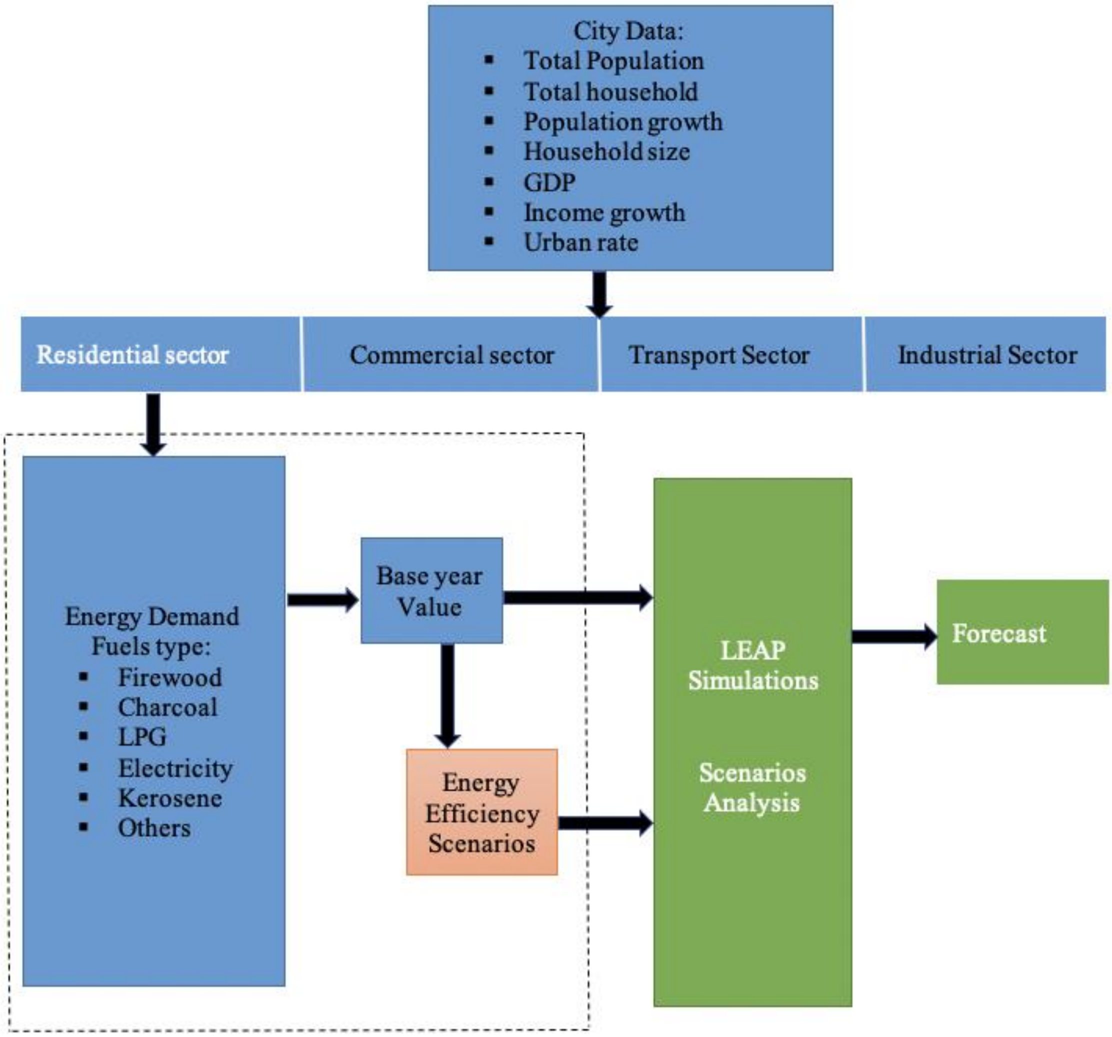

Figure 3. 18: The research framework of LEAP model

3.3. Sampling Determination and Data collection

The survey was conducted in Northern Province, of Rwanda, in Musanze District. Due to that, the Government of Rwanda, through MININFRA, initiated long-term green cities in order to fight against climate change in Rwanda, especially in secondary cities. Musanze city was selected for this research due to the fastest developing city behind Kigali. Hence, the secondary cities grow, energy demand will also grow. If energy is mostly sourced from renewables, then this in itself contributes to green growth.

As the Government of Rwanda and their key stakeholders, encouraged their people to use energy efficiently, the knowledge transfer and effective management can be easily disseminated. The main aim of this research was conducted in the different households to assess the energy efficiency practices in selected secondary city.

Therefore, a sample size of respondents was determined using Krejcie and Morgan table see annex 4 and the total numbers of 356 of household in Musanze city site, were selected randomly to respond to the questionnaires.

$S= [X^2 NP (1-P)]/ [d^2 (N-1) +X^2P (1-P)]$ (1)

Where: X: Table value of Chi-Square, with d. f=1 for desired confidence level of 0.05=3.84

N: Population size
P: Population proportion (assumed to be 0.50)
d: Degree of accuracy (expressed as a proportion, assumed 0.05)

S: Sample size (Krejcie, *et al*, 1970)

A household survey for Musanze city was done on a total of 356 Households were surveyed, and information about the number of household occupants, how much fuel is bought per month, and the number of different appliances for each end-use used in the household were recorded. Also recorded, was how often each appliance used on a daily basis in number of hours. The survey included numerous questions relating to quantities of fuel bought each month and how many appliances of each type the household had. Questions about how often the appliances a household had and used were also part of the survey. The household survey count and groupings by sectors address from the survey.

Therefore, a sample size determined of respondents in the respective sectors, are summarized on below table.

Sector	Muhoza	Cyuve	Kimonyi	Musanze	Total
Respondents	156	76	60	64	356

3.4. Data Collection Methods

The different methods used to gather the data included, the questionnaires; direct interview; and literature of the different books, programs related to energy efficiency and secondary cities planning in Rwanda.

Questionnaires*:* A total number of 356 questionnaires were managed to the household energy use selected randomly. The questionnaires have been used to enable the researcher to balance the quantity and quality of data collected and also to enable respondents to provide information about particular questions with a freedom by writing their opinions, views, perceptions, feelings, and experiences. And also, questionnaire used to know the costs or amount of different energy demand. To avoid bias during data collection, the original questionnaire was written in English language, therefore translated into Ikinyarwanda language, which is the mother tongue of the farmers. This helped the dwellers to understand well the content, and where the technical terms were somehow not understood well, a researcher was near of them to give much explanation.

Interview**:** A semi-structured and unstructured interview were used to gather the data. This kind of data collection was selected to allow the interviewees to express their mind freely in their own words and thoughts on how the energy policy enforcement may help the enhancement of energy efficiency. The interviews were addressed to District Energy Planner Officer, Chief of Executive of Energy Private Developers and 2 managers of energy private company in Rwanda (Geni and Inyenyeri).

3.5. Data collection

In order to feed the required input data into the simulation tool, LEAP-relevant data were collected mostly from survey and government agencies such as Rwanda Utilities Regulatory Rwanda (RURA), Rwanda Energy Group (REG), Ministry of Infrastructure (MININFRA), National Institute of Statistics Rwanda *(*NISR*)* etc. For economic parameters such as National GDP, GDP per capita, GDP growth rate and GDP by City, data were taken from the World Bank and Ministry of Finance reports. Most of the required data for the application of the LEAP model was available for the base year. However, for some input parameters, either the official data was not available, or it had not been updated. In such cases, either an assumption was made based on information available from previous years or data was collected from secondary cities.

3.6. Statistical Analysis

Preprocessing is conducted to change the row data to be able to use it in further modelling tool. The preprocessing is conducted by first filling the raw data in SPSS and MS excel then the data is analyzed. Then the mean value was used for further analysis and forecasting.

3.7. Scenario Description and Assumption

3.7.1. The Model

LEAP is a widely-used tool for energy policy analyst and climate change mitigation assessment (Heaps, 2013). The software can be used to created models in countries or regions. The structure of LEAP is flexible; the user will design energy, economic and environmental models. The energy supply required depends on how energy is demanded, transformed and generated in each specific case using economic variables that address the energy consumption**.** Figure 3.4 describes how LEAP works. Demographic data, energy scenario (assumptions) and macroeconomic data are the variables which conducted the energy demand. Energy transformation and supply energy depends on demand necessities. Finally, an environmental and cost-benefit analyst could be achieved in the process

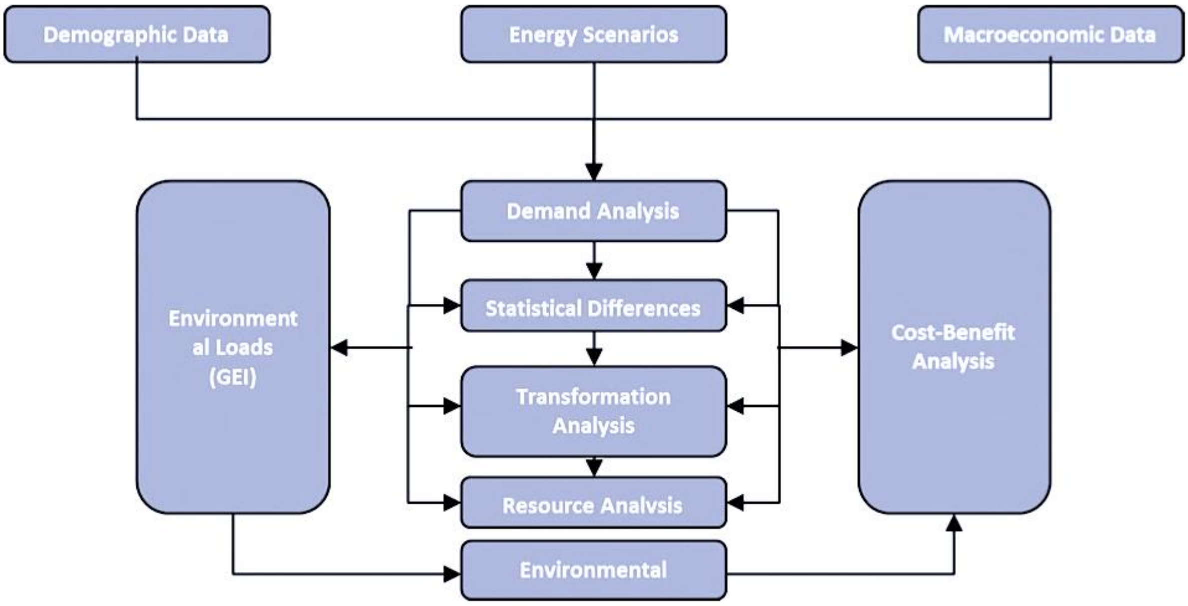

Figure 3. 19: LEAP Structure diagram

Demand: The technology in the model is a coupling of the macro-energy model and the structure of energy consumption of the economy. It is included a demand level in terms of different disaggregated final consumptions of energy in a way that converge to the macro-energy scheme. All the computations are determined by the levels of final demand. In this research only residential sector has been considered.

At the beginning is defined a sector (*i*) an activity (*j*), such that it is obtained a pair (*i, j*) that configures all the economy in terms of an energy final demand. Here, energy consumption (*EC*) is calculated as the product of a level of activity and the annual energy intensity (*EI*) or energy use by unit of activity. The final *EI* is the final annual average *EC* of an energy branch, when the source is a pure energy form, like electricity, the units must be of energy – and when the *EI* is specified for a branch of aggregated *EI*, the intensity can only be taken into account in energy units.

$EC = AL * EI.$ (2)

Where EC = Energy Consumption, *AL* = Activity Level, *EI* = Energy Intensity

$AL = \Sigma AL\ (i, j)$ (3)

The AL is a measure of the energy consumption in each economic activity. The demand structure analysis involves the levels of activity in absolute terms (*e.g.*, household's quantity) in a level of hierarchy and in both, share of participation and percentage of saturation in all hierarchy levels. In this way, the total activity shows the result of multiplying each one of the AL branch chains, with an associated speed of economy adjustment for a final *EI*. This is the annual average of final energy consumption for a branch of technology, but also can be defined in the immediate superior level as aggregated *EI*.

With this framework, the energy demand is calculated for the base year and for a future year in each scenario in the following way:

D (s, b, t) = TA (b, s, t) * EI (b s, t) (4)

Where: D = is Energy Demand, TA = is Total Activity , EI = is Energy Intensity , b = is the Branch , s = is the Scenario and t = Year (since year 0 until final year)

2.7.2. LEAP data requirement

A key benefit of LEAP is its low initial data requirements which depends on the type of energy modeling being carried out (i.e. bottom-up or top-down approach). However, the LEAP model requires a comprehensive knowledge on data collection, understanding of the energy system and time-consuming efforts especially in the data collection and input period. The type of data required for analysis on the LEAP model is described below and can be found in Heaps (2006).

2.7.2.1. Demographic Data

This is usually the general data of a country of which includes; national population data, rates of urbanization, average household sizes, household growth rate, population growth rate, and urbanization growth rates. In some modeling, population by region, male/ female population and age structure of population may be required. All this are entered into the "Key Assumption" of the data tree in the LEAP model.

2.7.2.2. Economic Data

The economic data include GDP/GNP data, value added by sector/subsector, average income levels, and interest rates. Other data include production of energy-intensive materials (output in tons or US$ per steel), transport needs (passenger-km, tonne-km, vehicle-km), income distribution.

2.7.2.3 General Energy Data

These are usually found in the National energy balances with data on energy consumption and production by sector or subsector in an economy. Most of these data are found in National statistical bodies or agencies or Energy related agencies as the country case may be. If the data are not available in the country, they may be available from the International Energy Agency (IEA) published energy statistics. Other data includes; National energy policies and plans, annual statistical reports with information on production, consumption, etc., of oil, natural gas, coal, charcoal, LPG, CNG, and other relevant fuel.

2.7.2.4. Demand Data

- Activity Levels: In LEAP's demand analysis, works by forecasting future energy consumption as the product of two factors: activity levels and energy intensities. Activity levels are simply a measure of the economic activity in a sector, and you can choose what data to use for this purpose. For example, in the household sector the user may choose to use the number of households as the activity level, in the cement industry you might use tonnes of cement production, and in the transport sectors you may choose to use tonne-kms (for freight transport) and passenger-kms (for passenger transport). The user will need to collect data describing the current, historical and future projections of whatever data the user chooses to use for his/her Activity Level variables. The user may need to consult national statistical reports or contact governmental or academic organizations working in specific sectors (industry, commerce, transport, households, etc.)
- Energy intensity data is often very hard to come by. If the user is preparing an aggregate analysis, he/she will likely be able to use combine their activity level data with national energy consumption statistics and energy balances to calculate historical energy intensity values by sector and by fuel.

  In other words, for historical data, *energy intensity = total energy consumption/activity level.* For your forward-looking scenarios you will instead use LEAP to calculate the total energy consumption by projecting the energy intensity and activity level. That is: *total energy consumption = energy intensity x activity level.*
- Other useful sources of energy demand data include recent social surveys or energy consumption surveys that analyze how energy is consumed in different sectors of the economy, and reports from utilities and private companies on sales of different energy

forms (electricity, natural gas, oil products). If possible, the user should try to get data disaggregated by sector and by consumer category.

If the user is creating a more detailed analysis, he/she will likely also need information on the stocks, technical characteristics (efficiency, specific fuel consumption), costs and environmental loadings of major energy consuming devices in different sectors. For example, if the user wants to focus on road transport energy use you would need data describing the stocks and sales of vehicles; there fuel economy, and some estimate of their average on-road life expectancy.

3.7.3. Reason for the Selection of the LEAP Model

The LEAP model has some advantages compared to other models mentioned in the last chapter (Chapter 2) and these were the basis for the selection of the LEAP model presented below.

- Work scope: the LEAP model is able to work its way up from energy extractions, processing, conversion, transmission, up to end-use consumption by demand devices, under a range of assumptions.
- Data characteristics: the LEAP uses a flexible data structure which can be a Top-Down or Bottom-Up approach depending on the data available, or even decoupling approach.
- Policy analysis: with LEAP, an energy policy analyst can develop and evaluate alternative scenarios by comparing the energy requirement, social costs and benefits, and their environmental impacts.
- Technology and Environmental Data (TED): the LEAP model is integrated with TED databases which gives users information regarding technical characteristics, cost, and environmental effects of energy technologies.
- Graphical interface: The LEAP's interface is user-friendly, rich in technical specifications and end-use details.

3.7. 4. Scenarios

Energy Business as Usual (BAU) Scenario: The Business as Usual Scenario is a consistent description about how the Musanze urban energy system will develop in the future in the absence of new and explicit energy efficiency policies and mitigation measures.

- Urban household's electrification will change from 42% nowadays to 100% in 2024.

- The energy intensities (KJ/household), measured in terms of useful energy, will grow according to the evolution of GDP/household, with an elasticity of 0.83 for the urban households.
- There is expectation of a higher per capita incomes, with a moderate growth in the use of electric devices in urban households.

Energy efficiency Scenarios under this scenario, 3 different sub-scenarios have developed:

- **Efficient Lighting Scenario:** Lighting is also one of the activities that consumes significant amount of energy in Musanze However, it is obvious that there are some of the households use the less efficient incandescent light bulbs. Therefore, the replacement of those light bulbs with more efficient compact florescent or LED light bulbs is vital. This would save significant amount of energy of the households.

- **Sustainable Biomass Usage scenario:** This scenario looks at better usage of wood and charcoal in Musanze in order to save on wood and charcoal usage. This scenario is constructed in line with the SE4ALL goals on reducing reliance on biomass by efficient use of the fuel, and falls within the same scope as the Biomass Energy Strategy (BEST) for Rwanda (MININFRA, 2015). Various types of Improved Cook Stove (ICS) initiatives have been introduced to reduce the demand for biomass consumed for cooking, whilst increasing efficiency and decreasing health damage at the same time. Household penetration is currently estimated at 70%, although it is assumed this doesn't include replacement.

  This scenario looks at a program to replace all wood or charcoal stoves with efficient ones, starting in 2020 and finalizing by 2040. These efficient stoves will have assumed efficiency gains. In this scenario it is assumed new stoves are rolled out and people using them are trained or educated on how to most effectively use them.

Figure 3. 20: Cookstove workshops in Rwanda

Efficient charcoal cookstoves in this scenario for households are assumed to use 40% less charcoal, and efficient wood stoves use 50% less wood. For costs, it is assumed that efficient stoves cost 17000 RWF. The same cost is assumed for wood burning stoves.

- **LPG Usage scenario:** LPG is considered clean in terms of emissions and could be used for cooking and heating purposes. The SE4ALL report notes that LPG is considered a clean fuel, but Households consider it dangerous. The use of LPG in cooking has increased from 724.6 tons in 2010 to 2,808.43 tons in 2016.The LPG production from lake Kivu is growing which opens up the replacement of wood and charcoal by the cleaner gas. The gas can also be used for the generation of electricity but transforming one form of energy into another involved considerable losses.

  Mobilizing people to embrace LPG is one of the targets in performance contracts of local leaders countrywide. The growing demand is due to campaigns. Government scrapped value added tax LPG and cylinders. The price of gas has dropped from RWF 1,600 per kilograms in 2010 to RWF 1,100 in 2016 and gas cylinders, ranging from six kilograms are available on the market to ensure every Rwanda can afford LPG.

  This scenario looks at the possible gradual improved access to LPG as a fuel for cooking. More HHs use LPG, replacing wood and charcoal stoves (not necessarily all of them) with LPG burning stoves.

CHAP IV. RESULTS INTERPRETATION AND DISCUSSION

4.0. Introduction

This chapter describes the results found, on the different impact of energy efficiency policies on future energy demand in secondary cities, with reference to the selected city.

4. 1. Household Energy consumption

The data collection on energy consumption in Musanze city produced extremely rich quantitative and qualitative data. Here there are some highlights of the most interesting and robust insights, focusing on energy sources, fuel consumption costs, and energy use/technologies.

The characterization of the respondents based on the identification of their sex and sector location education and description of their frequent farming activities. Hence based on the results, a total number of 356 respondents participated in this research, 44% were from Muhoza sector while 26% were from Cyuve Sector, 15% were from Kimonyi sector and 15%of the respondents were the farmers Musanze sector.

On the other hand, gender balance is the key important issue in irrigation performance. As indicated from results, 57.89% of total respondents were female while 42.11% were male see (figure 22).

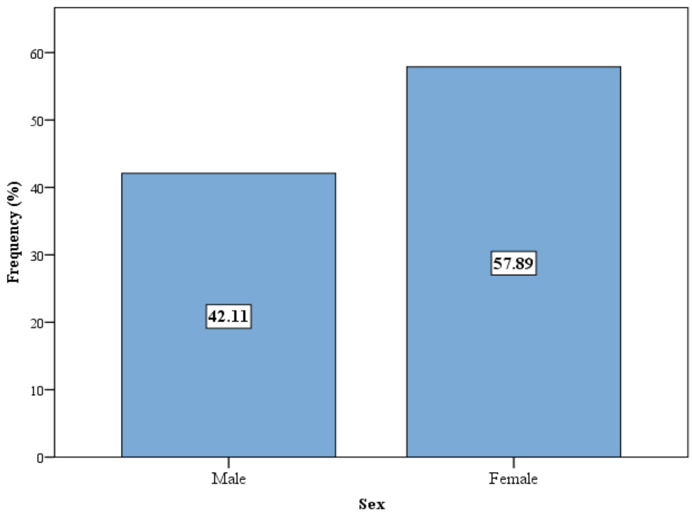

Figure 4. 21: Gender share of the respondents

Based on our sample of 356 households, four main energy sources predominate in Musanze city: electricity, charcoal, candles, LPG and firewood, (see Figure 23). Urban household energy consumption patterns are different. Electricity (97.89%), candles (44.21%) and liquefied petroleum gas, or LPG (37.89%). Charcoal use is much higher, at 82.11%, whereas firewood use is only 29.49%.

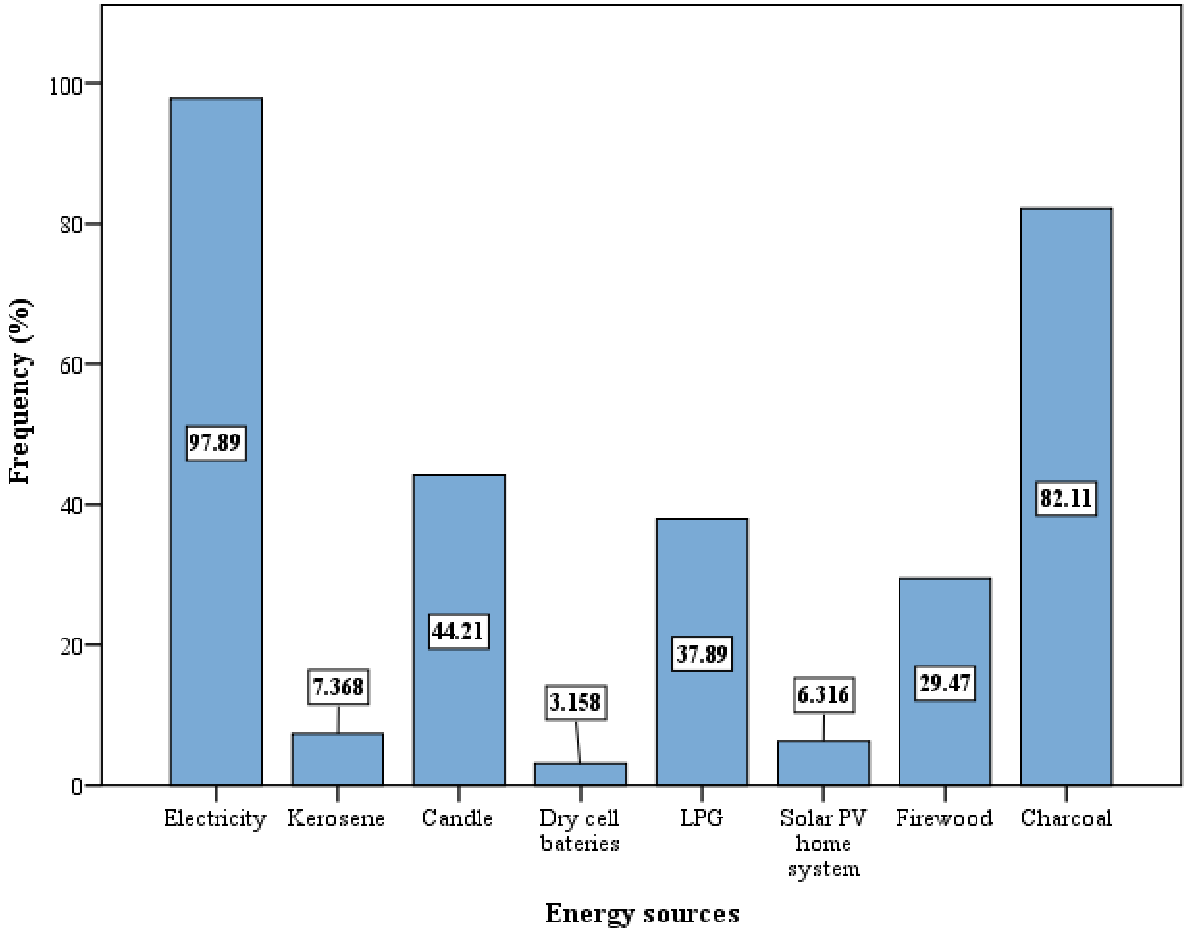

Figure 4. 22: Energy consumption in urban

The figure for charcoal consumption in urban areas is very high compared with the roughly domination while firewood dropped compared to Rwandan 4th Population and Housing Census, 2012 (NISR) where the main sources of energy for cooking used households varied by area of residence. In urban areas, households used more firewood (48.6%) and charcoal (48%).

The data raise questions that require further investigation. For instance, why is the use of candles so prevalent in urban areas? Is it because they are more easily accessible and/or cheaper in urban areas? Is it because electricity supply? which is largely confined to urban areas is unreliable, so candles are often needed during power cuts. From the interviews and they have common complaints about poor electricity service and many power interruptions. In 2012, the Rwandan government has promoted using efficient lighting technology to reduce household lighting consumption. Lighting is one of the energy demanding activities in households. Its energy source is electricity for grid connected households. The survey shows that three types of electric lamps have been used in households namely: incandescent light bulb, energy saving light bulbs and florescent light bulb.

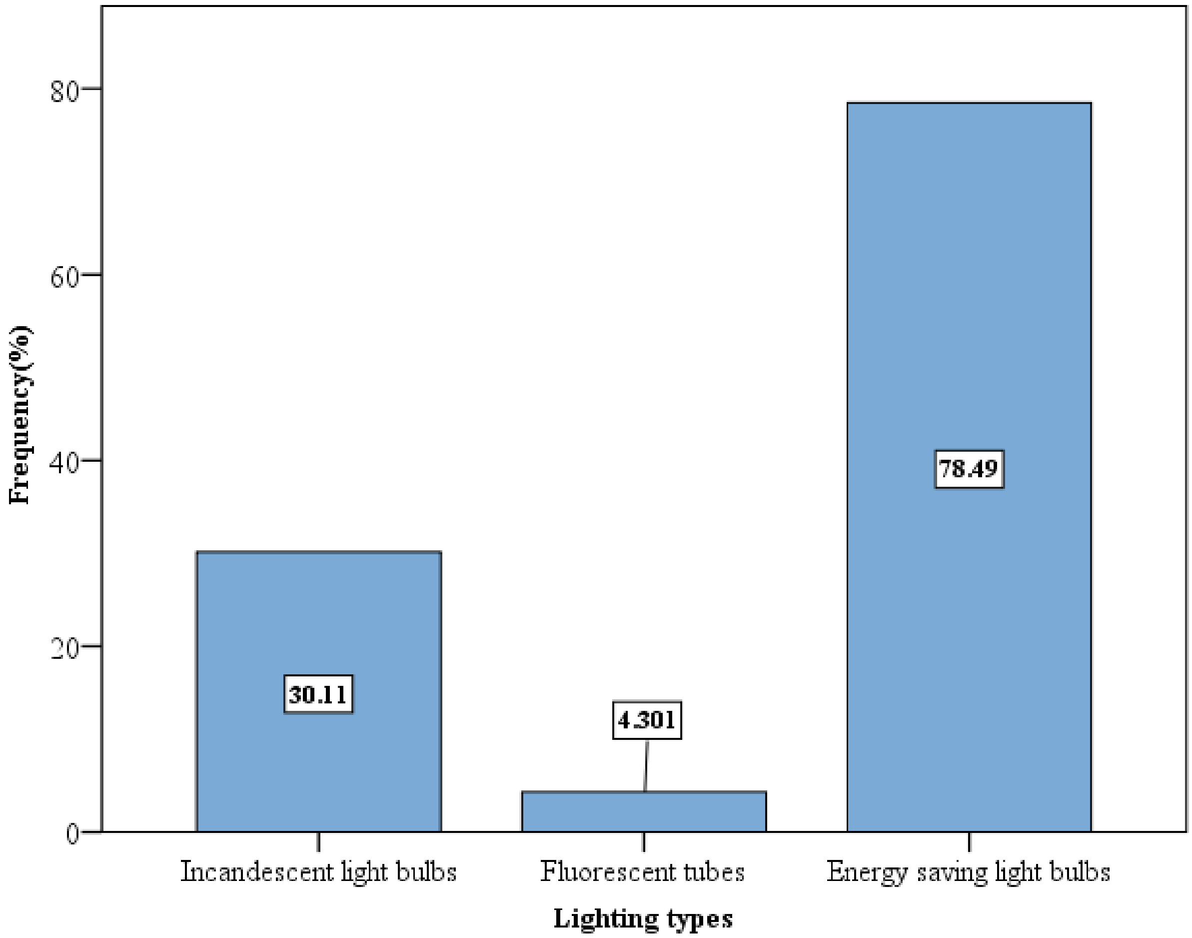

Figure 4. 23: Lighting types share

From the survey the results showed that the energy saving light is dominating with 78.49% but there are 30.11% household still using incandescent lamp (see figure 24).

In this research it was found that four main electric appliances predominate in Musanze city: radio, tv, sound equipment and electric iron (see Figure 25). Charcoal use is much higher, at 82.11%, whereas firewood use is only 29.49%.

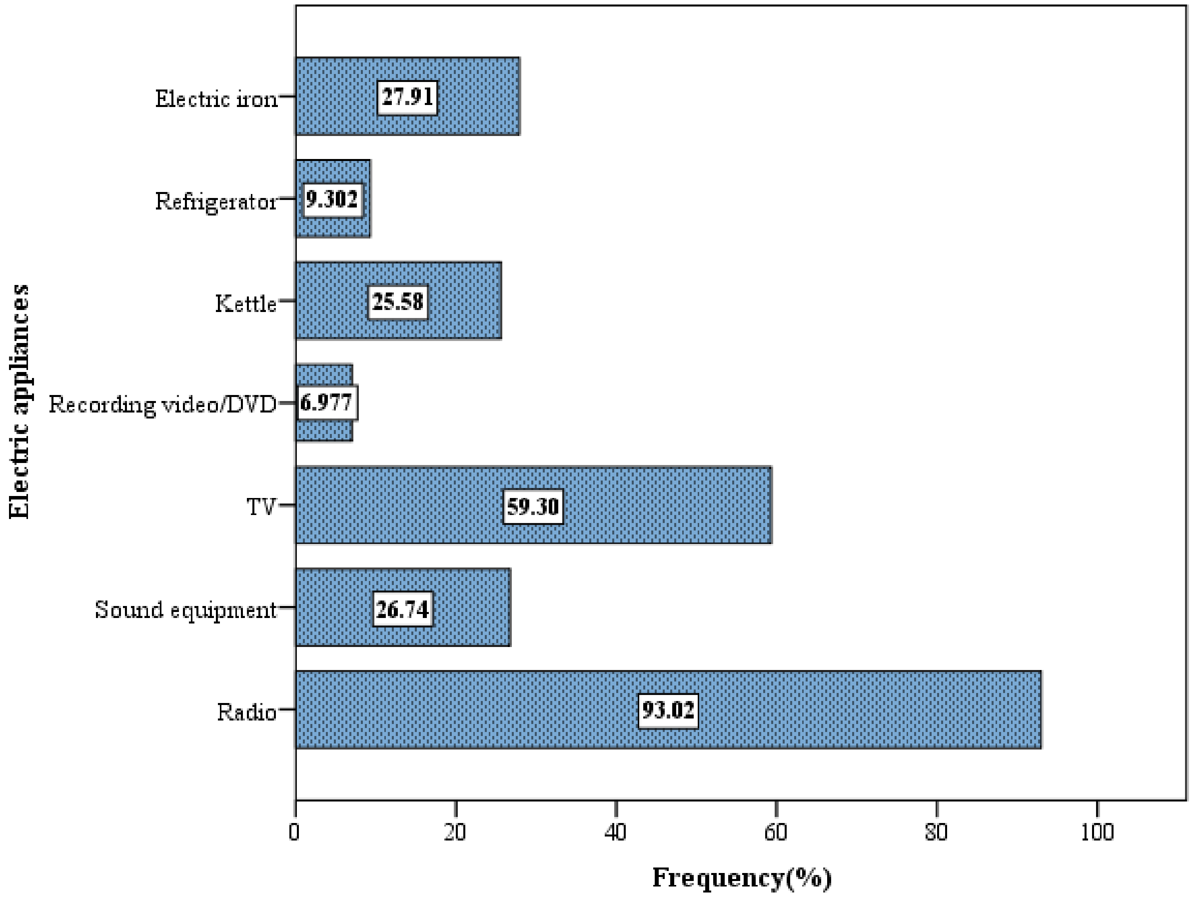

Figure 4. 24: Household electric Appliances

The results showed that Musanze urban households have different appliances. Radio dominates (97.89%) and followed by TV with 59.30%, and electric iron with (27.89%). They have not much fridges they usually cool the products by nature because Musanze is cold place.

The figure 26 shows the results from the research that the technologies used for cooking food in Musanze city, about 40% are using tradition stoves without chimney, 23.16% are exercising improved stoves, 20% have gas/kerosene stoves, 11.58% are cooking by means of three stones and 5.26% cook their meal tradition stoves with chimney.

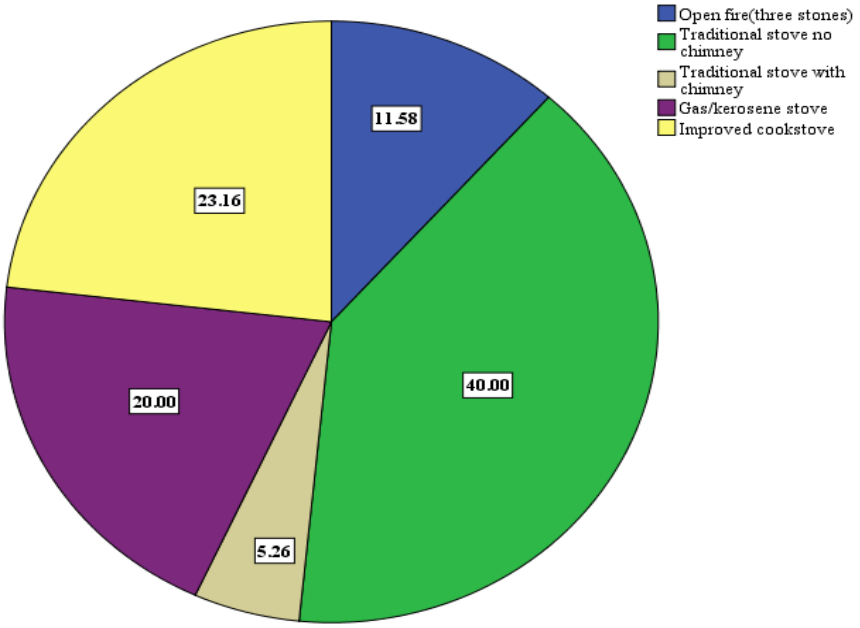

Figure 25: Households Cooking stoves shares in percentage

There are not electric stoves found in survey people do not cook with electricity because the price of electricity per KWh is high.

4.2. Scenarios and forecasting results

4.2.1 Business As Usual (BAU)

The following results have been obtained from the simulations using LEAP software. At BAU scenario, the annual energy demand in Musanze households to 2040 is illustrated in figure 27 with charcoal that will be the main consumer. As shown in figure 26, out of 88.7 thousand GJ energy consumed by the household in the base year, 51.7% was share of charcoal and 37.9% was firewood usage, while the demand for modern fuels such as kerosene, LPG and electricity were not high all stood at 10.5%.

With BAU scenario in 2040, the charcoal will be dominating the energy fuel demand with 68%.

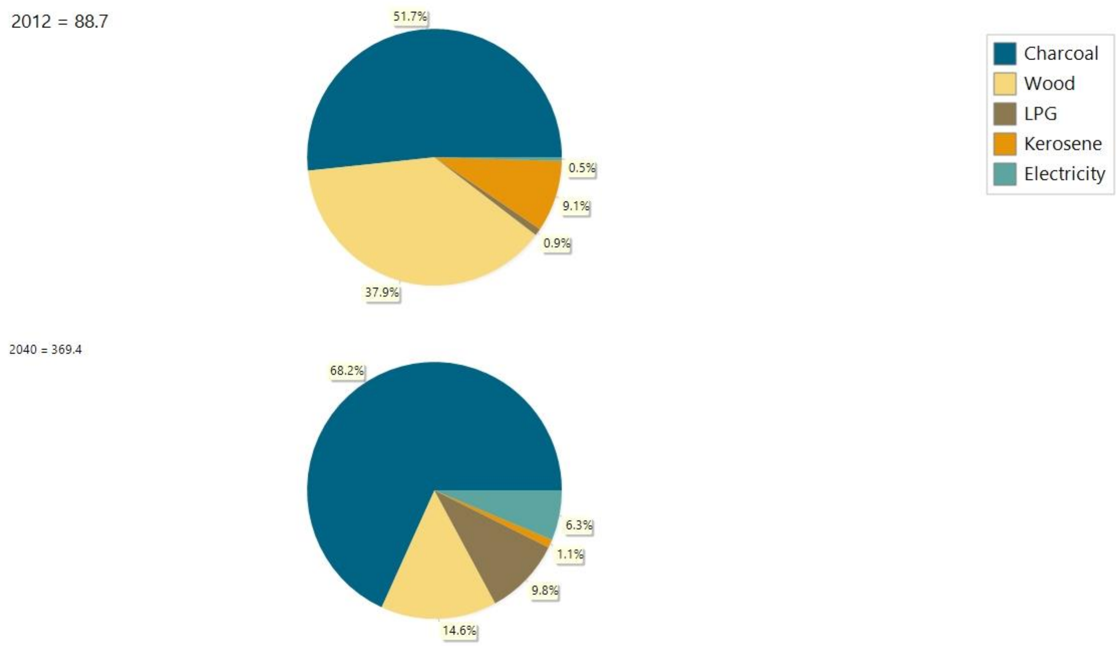

Figure 4. 26: Household demand fuel shares at BAU

As the total energy demand increases, the cooking energy demand of the residential sector also increases. Final energy demand for cooking activities increases continuously and is estimated to have a big share.

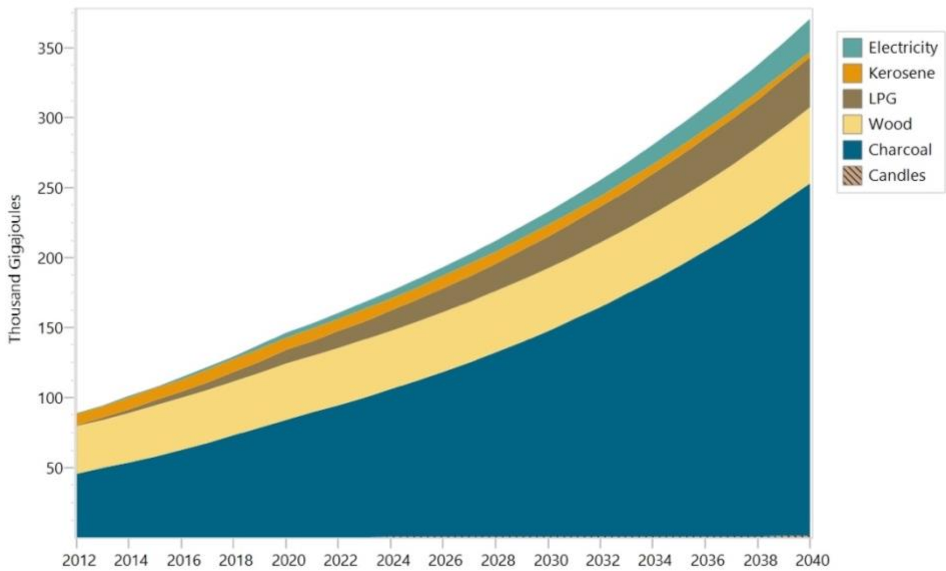

Figure 4. 27:Forecasted energy demand fuel at BAU

The consumption trend analysis in energy household activities by fuel types shows that traditional energy sources such as fuel wood and charcoal contribute the highest share, at 89.5%, while the share of modern energy fuels such as kerosene, LPG and electricity remain 10.5% in 2040. Figure 28 shows the demand trends of LPG and electricity in the BAU scenario where both modern cooking fuel demands increase over the outlook period.

4.2.2. Energy efficiency Scenarios

In this scenario, it has been explored the impact on fuel consumption in the household sector of an increase in access and utilization of modern energy fuels for cooking – mainly LPG and electricity. The number of households utilizing clean fuels increases in this scenario (EES) starting in 2012 through to 2040. We assume that most households would prefer to cook on gas (LPG) than electricity as there are a number of them already using LPG for cooking, while the use of electricity for cooking is virtually non-existent. The uptake in the number of households using these fuels is presented in the figure 29 below.

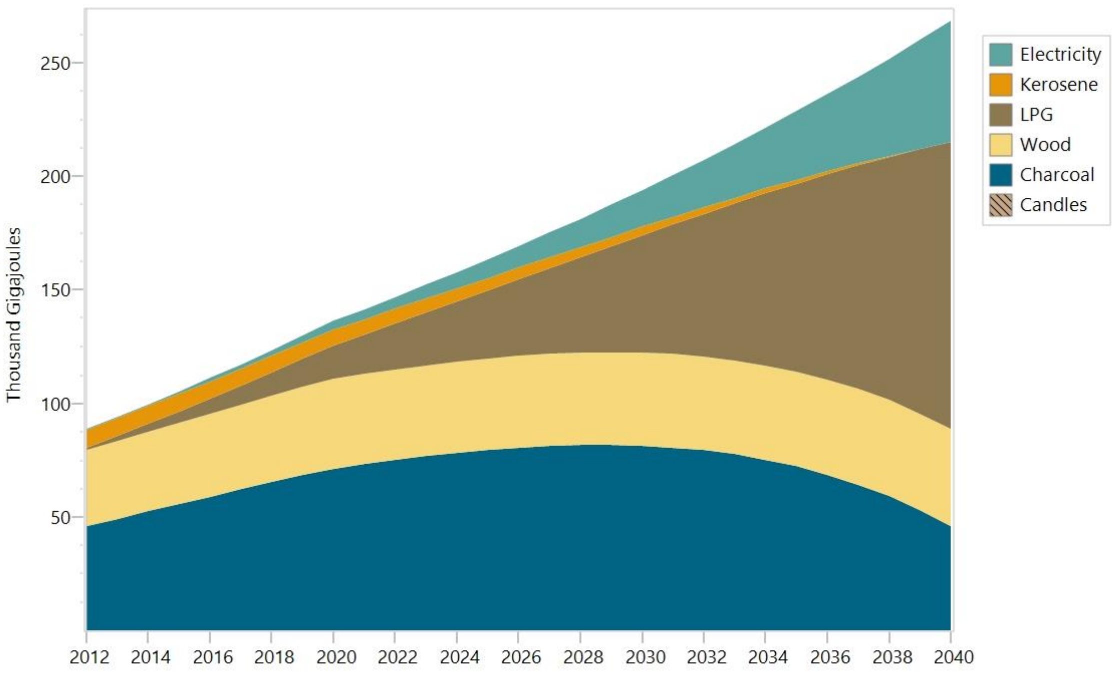

Figure 28:Forecasted energy demand fuel at EES

By comparing BAU and EES forecasted energy fuel demand by 2040, on the figure 30 the results found show that total demand is 369.4 thousand Gigajoules on business as usual scenario, instead total final energy fuel is 268.5 thousand gigajoules on Energy efficiency Scenarios. That means that about 27.5% will be saved by using energy efficiency policies.

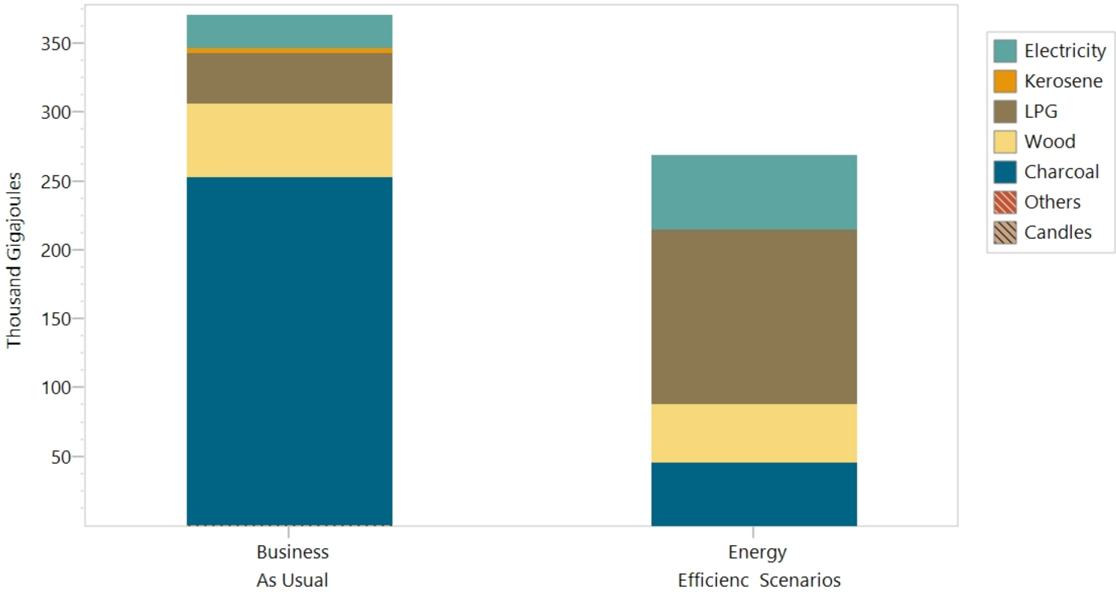

Figure 29: The comparison forecasted energy fuel shares between BAU and EES in 2040

On the hand BAU scenario will be higly dominated with traditional energy at scale of 82.7% such as charcaol with 68.1% and firewood that has share of 14.6%. While EES will be led by mordern fuels at rate of 66.9% where LPG will have 47% total demand and electricity with share of 19.9%. That means in 2040 Musanze households will be using more clean fuels by implementing energy effiency policies.

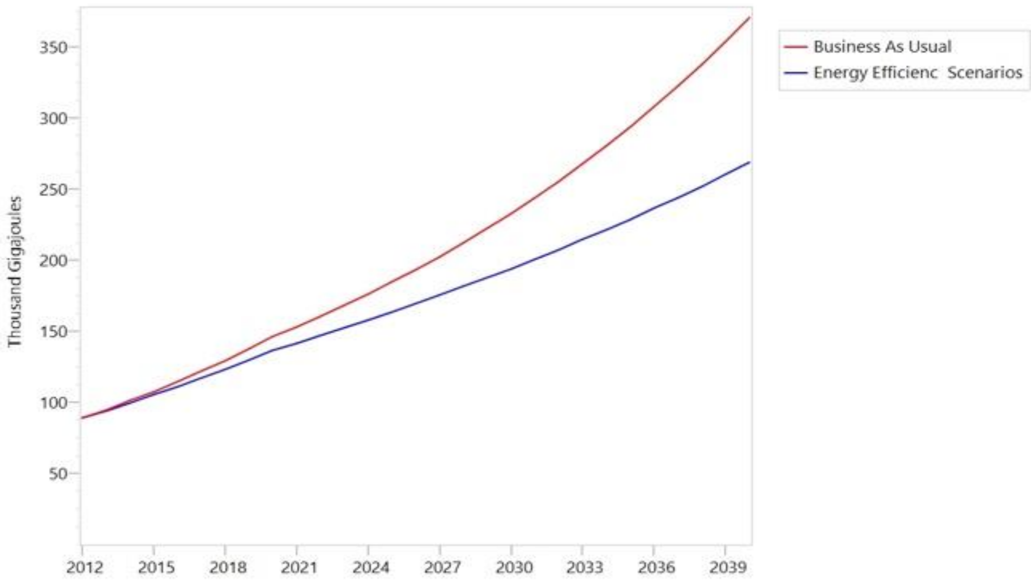

Figure 4. 30. Forecasted scenarios trends

The results show that the total energy consumption difference between the two scenarios is 100.9 thousand Gigajoules by 2040, but there is a deviation in total energy consumption between 2012 and 2040 as you can see on the figure 32.

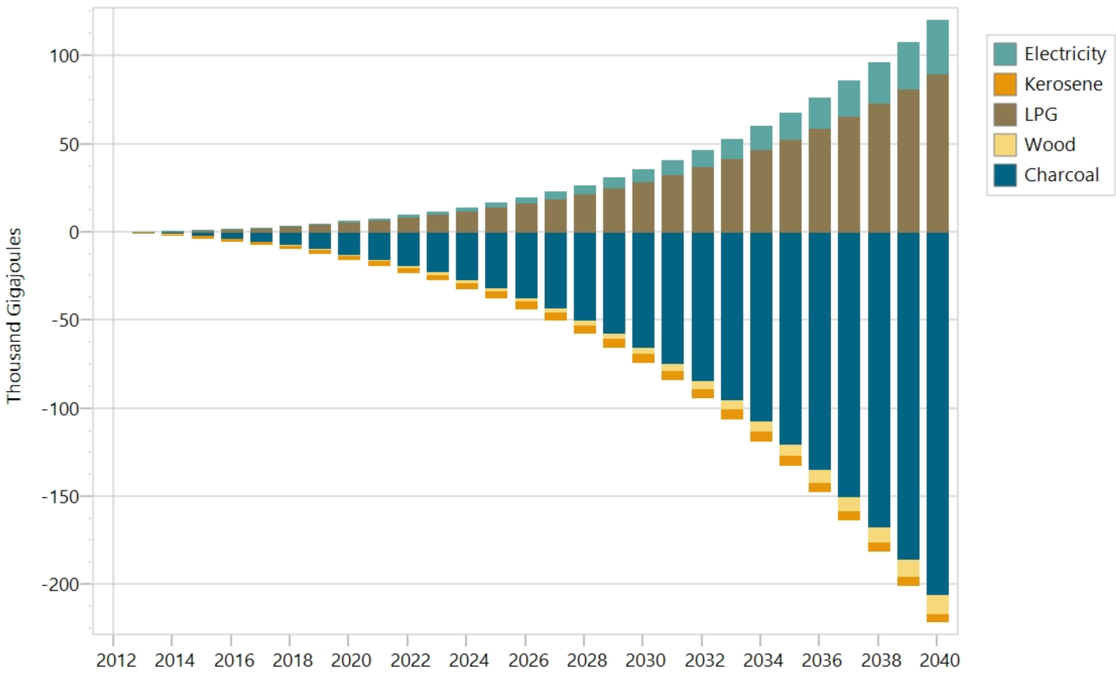

Figure 31: BAU vs EES energy demand fuels

4.3. Energy cost savings

The investigation was done to identify the cost saving from implementing energy efficiency policies. The results showed that on BAU Scenario the cost is 19.4 million USD while on EES scenario is 12.2 million USD in 2040. By implementing the energy efficiency policies about 7.2 million USD can be saved. This was showed that there is a decent potential for energy savings in the energy efficiency. On the national level savings from the total energy consumption in the secondary cities can be achieved by implementing some energy efficiency policies.

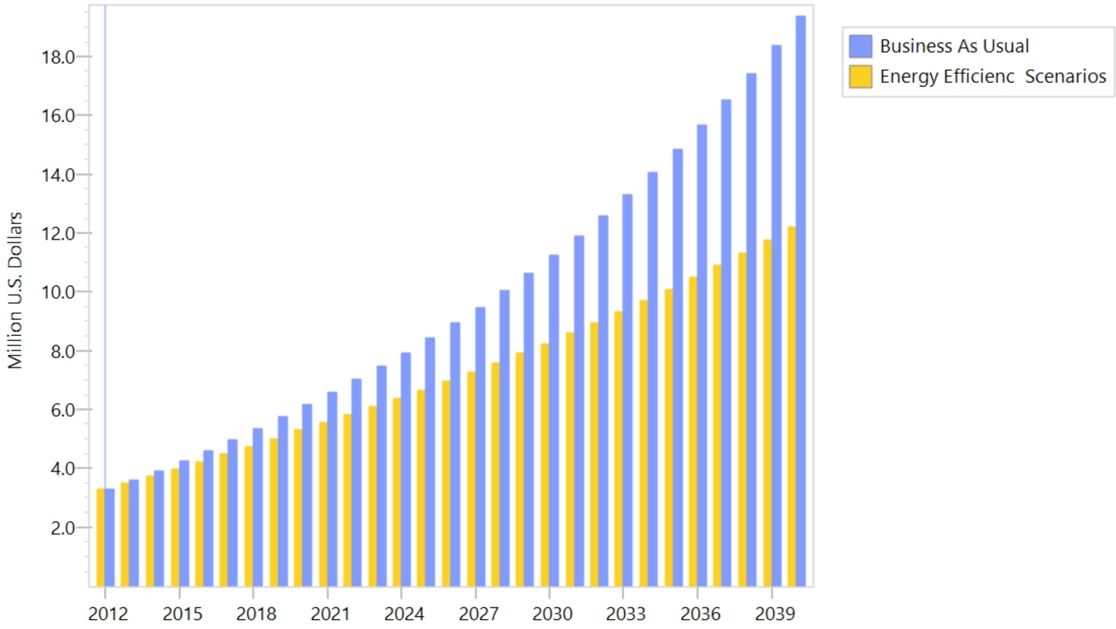

Figure 32: BAU vs EES energy cost savings

4.4. Barriers and Drivers for Energy Efficiency Policies

An interview conducted on the different energy managers and expert's association leaders in their respective expertise area the different strategies aiming at enhancing energy efficiency in secondary cities in Rwanda. From interviews, different barriers and drivers have found during research.

4.3.1. Barriers

- **Policy barrier:** Although several Rwandan government policies mention energy efficiency, the country has no specific way of implementation dedicated energy efficiency policy.

- **Informational barriers:** These barriers relate to the dissemination of information regarding energy efficiency among all stakeholders throughout the energy efficiency supply chain, from policy makers to end-users. People have to be informed about energy efficiency technologies and their advantages. A special focus has to be given to information and communication activities with the aim of raising awareness about energy efficiency technologies, their benefits and the role of energy efficient user behavior.

- **Institutional barriers:** So far, in Rwanda, the electricity utility (REG) is the sole institution with a significant role in energy efficiency issues, with support from MININFRA. However, for energy efficiency activities to be effective in a country, there generally should be a dedicated institution or agency or body in a suitable part of the government structure with a leading agency mandate and a suitable budget to work as the energy efficiency champion and flagship leader. The lead energy efficiency institution or agency must have the right mix of suitably skilled human resources and adequate funding to effectively fulfil its role. While being an active participant in developing the practical aspects of energy efficiency policies and managing suitable energy efficiency programmes and projects, it would also have a leading role in conducting energy efficiency training and awareness campaigns.

4.3. 2. Drivers

- **Energy efficiency experiences:** Rwanda already has experience in energy efficiency projects from implementing a compact fluorescent lamp (CFL) distribution programme, which is pending completion. The country can capitalise on this experience by developing a wide range of appropriate new programmes and projects to be implemented.
- **Higher in energy prices:** Though the present vision 2020 has a target to reduce electricity supply cost, it has been increased in July 2012 by 20%. Electricity tariffs in Rwanda are considered among the highest in East Africa. Energy efficiency improvement lowers electricity bills for end- users, and electricity savings are one of the most important drivers of energy efficiency in all sectors.
- **Non-energy benefits:** These benefits refer to advantages gained from energy efficiency rather than energy savings and the related cash flow savings. They include environmental improvements, energy security, job creation, green growth, branding,

etc. A reduction in energy consumption automatically creates a reduction in GHG emissions. Energy efficiency reduces the need to import fossil fuels, thus reducing the country's dependence on other countries. Promoting energy efficiency will lead to job creation in a field where capacity is very low in Rwanda, promote green growth and improve the branding of Rwanda as a country that is going green.

- **Lake Kivu gas extraction to LPG:** The Government of Rwanda represented by the Rwanda Mines, Petroleum and Gas Board (RMB, and the Rwanda Development Board (RDB) signed a deal with Gasmeth Energy Limited that will see the latter extract and process methane gas from Lake Kivu. Gasmeth Energy plans to finance, construct and maintain a gas extraction, processing and compression project. The project will include a gas extraction plant on Lake Kivu, where Gasmeth Energy will extract and separate methane gas from water and thereafter transport it to an onshore plant where they will compress it. The compressed natural gas will be distributed on both the local and international market.
- **Load shedding:** There are power shortage in Rwanda. Therefore, there is regular power shedding in order to respond to the insufficient power supplies. Energy efficiency will be a powerful tool to help the electricity utility reduce peak demand. It should be kept in mind that hydro power plants installed in Rwanda are the run-of-the-river kind without any storage. This means that the half of the power production is highly vulnerable to the level of water in the dam. Energy efficiency will help mitigate the risk associated with power generation from hydro.

CHAP V. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study assessed the impact of energy efficiency policies on future energy demand in secondary cities, in Musanze-Rwanda. The results showed that four energy sources predominate: electricity, charcoal, firewood and LPG. However, there were urban households with greater diversity of energy sources in urban households, also including electricity (97.89%), candles (44.21%) and liquefied petroleum gas, or LPG (37.89%). Charcoal use is much higher at 82.11%, whereas firewood use is only 29.49%. The study evaluated the forecast of energy consumption based up on various scenarios. The analysis result of the study with a Business as Usual Scenario shows that as the result of the growth of the economic sector, urbanization ratio and the living standards of people, the demand for energy is increasing very fast while the energy supply is going short as the result of the unsustainable use.

The demand of modern fuels such as LPG, kerosene and electricity are increasing, and the analysis shows that the demand of both LPG and electricity would increase significantly. The results found show that total demand is 370.4 thousand Gigajoules on business as usual scenario, instead total final energy fuel is 268.5 thousand gigajoules on Energy efficiency Scenarios. At Energy Efficiency Scenario will be led by mordern fuels at rate of 66.9% where LPG will have 47% total demand and electricity with share of 19.9%. This study showed that with effective implementation of the energy efficiency policies would save about 27.5% of energy and reduce energy fuel demand in 2040. About 7.2 million USD can be saved as benefit from energy efficiency.

The limitation of the study is uncertainty and lack of similar consistent previous historical data the few studies conducted previously could not reveal the end use energy consumption with in various end use categories of the energy consumption sector in the households.

5.2. Recommendation

In order to minimize energy loss in urban households, this research suggests that:

- Similar studies in the future may focus more on obtaining previous data, if possible, the study could be conducted over years to use own primary data, or else obtaining as many years' data as possible to forecast the future energy consumption accurately.
- Energy institutions in the country should increase awareness of energy savings to the people. It must be emphasized that many households may not understand the technicalities in saving a unit of energy.
- For energy savings, more and better data and information are needed on energy end use and the usage of energy-consuming products. It could be important to develop a data base of energy efficiency indicators for Rwanda for data availability.
- Effective implementation of policy and legislation on energy efficient cooking technology is required for whole elimination of inefficient household cooking devices
- Establishment an institution for promoting energy efficiency policies. The creation of a dedicated energy efficiency institution or agency with a suitable mix of skilled professional staff and suitable ongoing funding will be a key component in any effective long-term energy efficiency policies approach in Rwanda.

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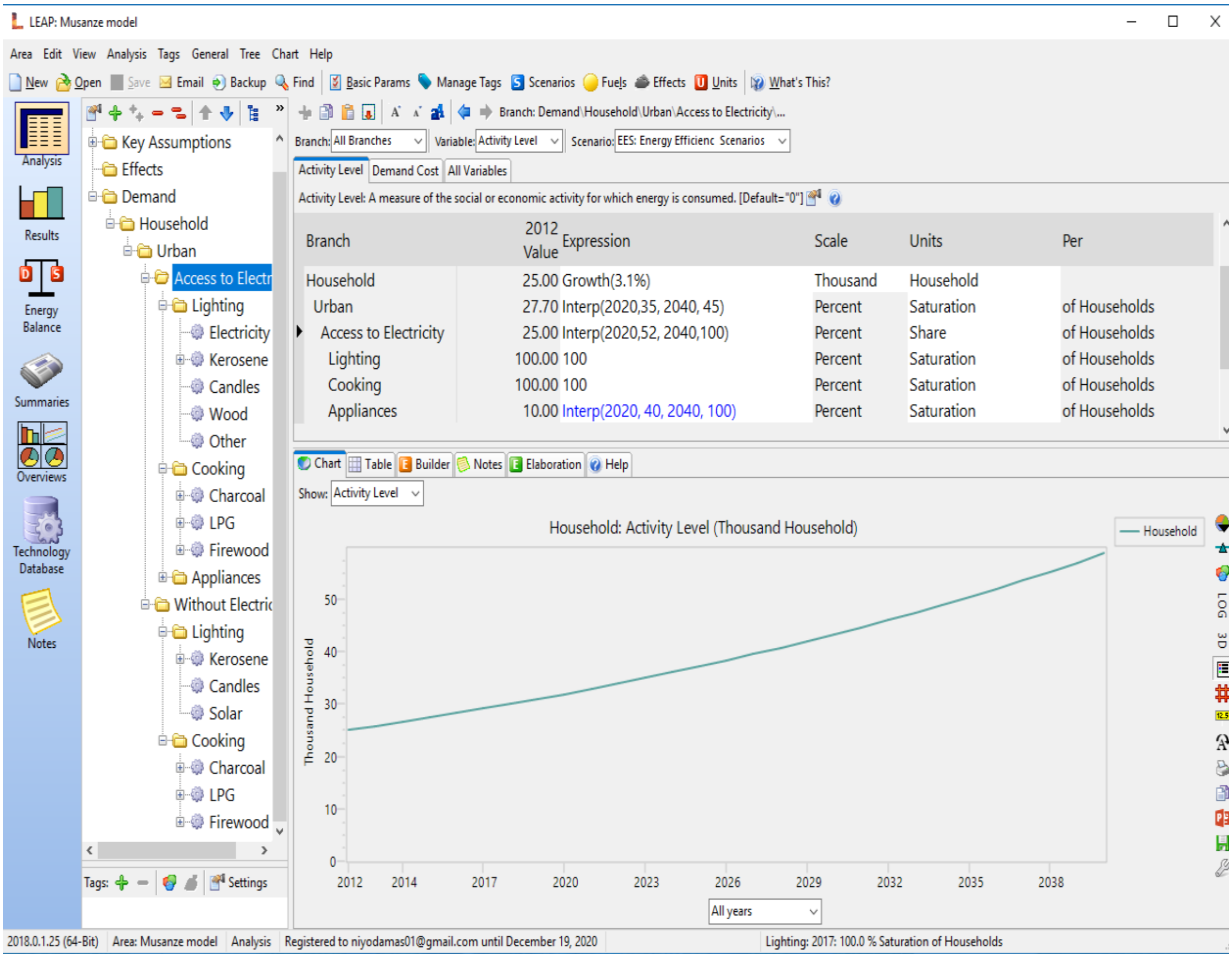
Annexes

Annex 1: LEAP Model software



Annex 2: QUESTIONAIRES

Address	
Survey Date	
Enumerator name	
Respondent name	

1	**Are the following energy sources used in your home?**	**Yes**	**No**
a	Electricity from interconnected grid or isolated system		
b	Kerosene		
c	Candle		
d	Dry cell batteries		
e	Car batteries		
f	LPG		
g	Solar PV home system		
h	Firewood		
i	Animal dung		
j	Crop residue		
k	Electric generator set		
l	Charcoal		
m	Peat		
n	Other (specify)		

2. What is the average usage and payment for one month (30 days) of electric service?			
Usage (KWh)		Cost (RWF)	
Does not know		Does not know	

3A. Does your household use any of the following types of lighting?				**3B. If yes, how many light bulbs of this type does the household use?**	**3C. What is the sum of all hours for all bulbs used during the last 24-hour period?**	
	Yes	No	Does not know		Hours	Minutes
Incandescent light bulbs						
Fluorescent tubes						

Energy saving light bulbs						

4A. Does your household use electricity for the following purposes?			**4B. In general, how many hours per day for each activity?**	
Use type	Yes	No	How many hours	Does not know
1. Lighting				
2. Cooking				
3. Electric appliances				
4. Other ______________ (Specify)				

5**. In case of power failure, what backup equipment does the household use, if any?**		
	Yes	**No**
a. Candles		
b. Kerosene wick lamp		
c. Gas lamp		
d. Dry cell batteries		
e. Car/Motorcycle battery		
f. Generator		
g. PV Solar system		
h. Other _____________________(Specify)		

5A. Does your household use the following plug-in electric appliances?			**5B. How many of each appliance does the household use?**	**5C. What is the sum of all hours for all appliances used during the last 24-hour period?**	
Appliance Type	Y	N		No. of hours	No. of minutes
a. Radio					
b. Sound equipment					
c. TV					
d. Recording video/DVD					
e. Kettle					
f. Refrigerator					
g. Microwave ovens					
h. Electric stoves					

i. Electric iron					
k. Fan					
l. Washing machines					
m. Domestic water pumps					
n. Others?__________ (Specify)					

6A. What is the main stove that your household uses to cook all meals? **Enter only ONE**		**6B. What type of fuel does your household usually use with this stove?**		**6C. Does your household use any other kind of fuel with this stove?**	
Open fire, e.g. three stones		Firewood		Firewood	
Traditional stove no chimney		Crop residue or wood chips		Crop residue or wood chips	
Traditional stove with chimney		Dung cakes		Dung cakes	
Gas/kerosene stove		Charcoal		Charcoal	
Improved cookstove		Coal		Coal	
Electric stove		Kerosene		Kerosene	
Other	__________ (Specify)	LPG		LPG	
		Electricity		Electricity	

7A. In the past month did your household use Kerosene at home?	
Yes	
No	

7B. How many litres of kerosene do you use per month?		**7C. What is the price of each litre of kerosene?**	
Litres		RWF per litre	

7D..Does your household use kerosene for the following purposes?			**7E. On average, how many hours for each activity?**	
	Yes	No	Average hours	Does not know
1. To start firewood				
2. Lamp lighting				
3. Cooking				
4. Other (specify) _______________				

8A. In the past month did your household use LPG at home?	
Yes	
No	

8B. What size of gas cylinder/tank does your household use at home?			**8C. What is the price per cylinder or tank of LPG?**	**8D. How many days does one cylinder of LPG last?**
	Y	N	Enter price in RWF per cylinder	Enter number of days one cylinder
1. 6 kg Cylinder				
2. 13 Kg Cylinder				
3. Other specify size in Kg of cylinder ______________				

9A..In the past month did your household use charcoal at home?	
Yes	
No	

9B. What size of charcoal does your household use at home?			**9C. What is the price of charcoal?**	**9D. How many days does one cylinder of 100kg last?**
	Y	N	Enter price in RWF per sack	Enter number of days one sack
1.10 kg Charcoal				
2.100 Kg Sack				
3. Other specify size in Kg of pack ______________				

10A. In the past month did your household use firewood at home?	
Yes	
No	

10B.What size of firewood your household use at home?			**10C. What is the cost per bundle of firewood?**	**10D. On average, how many days will this bundle last?**
	Y	N	Enter price in RWF per bundle	Enter number of days firewood lasted.
1. 5kg				
2. 10Kg bundle				
3. Other specify size in Kg of firewood____________				

Annex 3: Thesis budget

S/NO	ITEM	UNIT	QTY	RATE (UNIT PRICE)	AMOUNT (USD)	Link to research Activity	Comment
	(A) Material and Supplies						
1.	Internet and communication	Internet bundles monthly	4	27	112	The research will be considering different literature review from different online papers and sending report to PAUWES and supervisor. A good communication is needed to do a quality research	
2	Stationery, printing and photocopying	papers	4200	0.12	504	Printing questionnaire, internship and thesis reports and purchasing stationery to be used during data collection.	
	Sub total				**616**		
	(B) Equipment						
3	SPSS software		1	199	199	https://www.ibm.com/products/watson-studio-desktop/pricing SPSS software data analysis monthly subscription for data analysis.	
4	Data Collection (field transportation)		16days	25	400	The transportation involves picking researcher from the house to the field. The renting will cover the vehicle and its driver. It will assist movement in the 6 different cities during data collection from Kigali to Musanze, Musanze to Rubavu ,	
						Rubavu to Rusizi Rusizi to Huye, Huye to Muhanga, and Muhanga to Nyagatare.	
6	Data collection (4 field assistants)		4	140	560	Data collection assistants shall help me to end research on time.	
	Sub Total				**1159**		
	(C) Travel + Visa Costs						
7	Flight from Algeria to Rwanda		1	900	900	Qatar Airline ticket from Algiers to Kigali	
8	Taxi transport		1	45	45	Taxi ticket from Tlemcen to Algiers and from Kigali international airport to Musanze	
9	Flight insurance		1	80	80	Air Flight trip from Algiers to Kigali	
	Sub Total				**1025**		
	(D) Special Activities						
10	Publication		1	200	200	Publishing the results of the research in peer reviewed journal. And research report must be submitted to each secondary city, and 1 report to Rwanda Energy Group, according to the agreement of sharing the findings with the stakeholders in Rwanda	
	Sub Total				**200**		

BUGDET SUMMARY

TOTAL		
A. Material & Supplies	USD	562
B. Equipment	USD	1159
C. Travel	USD	991
D. Special Activities	USD	290
Grand Total	USD	**3000**

Annex 4: **Krejcie and Morgan Sample size determination table of known population**

Table for Determining Sample Size of a Known Population

N	S	N	S	N	S	N	S	N	S
10	10	100	80	280	162	800	260	2800	338
15	14	110	86	290	165	850	265	3000	341
20	19	120	92	300	169	900	269	3500	346
25	24	130	97	320	175	950	274	4000	351
30	28	140	103	340	181	1000	278	4500	354
35	32	150	108	360	186	1100	285	5000	357
40	36	160	113	380	191	1200	291	6000	361
45	40	170	118	400	196	1300	297	7000	364
50	44	180	123	420	201	1400	302	8000	367
55	48	190	127	440	205	1500	306	9000	368
60	52	200	132	460	210	1600	310	10000	370
65	56	210	136	480	214	1700	313	15000	375
70	59	220	140	500	217	1800	317	20000	377
75	63	230	144	550	226	1900	320	30000	379
80	66	240	148	600	234	2000	322	40000	380
85	70	250	152	650	242	2200	327	50000	381
90	73	260	155	700	248	2400	331	75000	382
95	76	270	159	750	254	2600	335	1000000	384

Note: N is Population Size; S is Sample Size *Source: Krejcie & Morgan, 1970*