MODELLING ENERGY SECTOR TOWARDS SUSTAINABILITY: PATHWAYS, LONG-TERM FORECAST AND MANAGEMENT SCENARIOS – A CASE OF EAST AFRICAN COUNTRIES

By

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DECLARATION

Declaration by the Candidate

This thesis is my original work and has not been presented for a degree in any other University. No part of this thesis may be reproduced without the prior written permission of the author and/or Moi University.

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DEDICATION

I dedicate this thesis, with special thanks, to my wife (Ndayishimiye Pacifique), our children (Manirambona Talia Gianna and Mugisha Talicia Aretha), my mother and siblings for their patience and the real support they gave me during all these years that have elapsed.

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ABSTRACT

A fast-growing energy demand is expected in East Africa due to its high population growth and socio-economic activities. However, energy planning is still relatively not developed in the region; hence, the need for robust energy planning policies in the region. The main objective of this study was to model East African energy sector pathways, long-term forecast and management scenarios. Specific objectives were to: develop energy mix model while controlling non-renewable energies; analyze current and future energy balance up to the year 2040; appraise different energy policies of the countries to develop renewable energies and improve energy efficiency; validate the model for long-term energy planning up to the year 2040. This research used Multi-Criteria Decision Making (MCDM) method and Long-range Energy Alternatives Planning (LEAP) model (Kenya and Burundi deeply analyzed in this research). Energy options were evaluated against four sustainable dimensions (Economic, Social, Environmental and Technical) combining 17 energy indicators and AHP–TOPSIS technique was applied. Energy policies (universal electrification-UE, efficient lighting-EL, efficient cooking stoves-EFCS and climate smart-low emissions-LE) found to be strategic priorities for the countries were analyzed. GHG emissions were determined in CO_2–Equivalent, 100–Year GWP (at point of emissions). Primary data were collected through a survey-questionnaire designed for energy experts in the countries and secondary data were collected from various sources. Results showed robustness of renewable technologies, particularly Solar PV in all analyzed scenarios (economic-privileged, technical-privileged, environmental-privileged, social-privileged, equal-importance). Also, LEAP results showed that total energy demand will keep rising: this was 178,993.9 TJ in 2015 and was projected to 417,980.0 TJ in 2040 for Burundi while it was 685,331.5 TJ in 2015 and projected to 857,518.3 TJ in 2040 for Kenya. From 2015 to 2040, households' energy demand is characterized by a slow growth with 1.36 times for Kenya and 1.31 times for Burundi; this demonstrated households' energy demand in saturation mode. Furthermore, households will remain the highest final energy consumers as their consumption was expected to constitute 79.6% and 53.5% of total demand by 2040 for Kenya and Burundi, respectively. EL-policy would enable to save 2,300.9 GWh and 124.6 GWh while EFCS-policy would save 190,556.4 TJ and 101,879.2 TJ by 2040 for Kenya and Burundi, respectively. With the EFCS-policy, 1,787.5 4 thousand-Metric-Tonnes (tmt) and 903.4 tmt CO_2–Equivalent would be avoided in comparison to Business-As-Usual (BAUS) by 2040 for Kenya and Burundi, respectively. Under UE-policy, households' electricity demand was projected to 6,845.0 GWh by 2030 for Kenya against 5,862.5 GWh under BAUS. Similarly, Burundian households' electricity demand would be 825.7 GWh by 2040 against 536.5 GWh expected under BAUS. LE-policy by phasing out all fossil-fired plants after 2030 was expected to cause Burundi import a significant amount of electricity while this policy would be implemented in Kenya without the need to import. In conclusion, total energy demand of the countries will keep rising and households are expected to remain the main total final energy consumers. The study recommends high adoption of renewable sources, EL-policy and EFCS-policies in the sustainable energy strategies of the countries.

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ABBREVIATIONS

ABER	:	Agence Burundaise de l'Electrification Rurale " Burundian Agency for Rural Electrification "
AHP	:	Analytical Hierarchy Process
ANP	:	Analytic Network Process
ARCH	:	Auto Regressive Conditional Heteroskedasticity
ARIMA	:	Auto Regressive Integrated Moving Average
EAC	:	East African Community
BRB	:	Banque de la République du Burundi " Bank of the Republic of Burundi "
CFL	:	Compact Fluorescent Lamp
CSP	:	Concentrating Solar Power
dESA	:	Division of Energy Systems Analysis
EEPCo	:	Ethiopian Electric Power Corporation
ELECTRE	:	Elimination and Choice Translating Reality
ENPEP	:	Energy and Power Evaluation Program
ETSAP	:	Energy Technology Systems Analysis Program
GARCH	:	Generalized Auto Regressive Conditional Heteroskedasticity
GDP	:	Gross Domestic Product
GIS	:	Geographic Information Systems
GWP	:	Global Warming Potential
HOMER	:	Hybrid Optimization for Multiple Energy Resources
IAEA	:	International Atomic Energy Agency
IEA	:	International Energy Agency
IED	:	Innovation Energie Developpement

INSP	:	Insititut National de Santé Publique " National Institute of Public Health "
IRENA	:	International Renewable Energy Agency
ISTEEBU	:	Insitut de Statistiques et d'Etudes Economiques du Buudni " Burundi Office of National Statistics and Economic Studies "
KNBS	:	Kenya National Bureau of Statistics
KPLC	:	Kenya Power and Lighting Company
KEREA	:	Kenya Renewable Energy Association
LEAP	:	Long-range Energy Alternatives Planning
LPG	:	Liquefied Petroleum Gas
MAED	:	Model for Analysis of Energy Demand
MARKAL	:	MARKet and ALlocation
MCDM	:	Multi-Criteria Decision Making
MESSAGE	:	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MWELMUP	:	Ministry of Water, Environment, Land Management and Urban Planning
NCSU	:	North Carolina State University
NPV	:	Net Present Value
ONATOUR	:	Office Nationale de la Tourbe " National Peat Office "
OnSSET	:	Open Source Spatial Electrification Tool
OSeMOSYS	:	Open Source energy MOdelling SYStem
PROMETHEE	:	Preference Ranking Organisation METHod for Enrichment Evaluations
PSI	:	Paul Scherrer Institute

PSO- ABC	:	Particle Swarm Optimization - Artificial Bee Colony
REA	:	Rural Electrification Authority
REGIDESO	:	Régie de production et de Distribution d'Eau et d'Eelectricité " National Utility for Production and Distribution of Water and Electricity "
SDG	:	Sustainable Development Goals
SEI	:	Stockholm Environment Institute
SE4All	:	Sustainable Energy for All
SINELAC	:	Société Internationale d'Electricté des pays des Grands Lacs " International Electricity Company of the Great Lakes Countries"
SNL	:	Société Nationale d'Electricté – DR Congo " Electric Unitilty Company – DRC Congo "
SWITCH	:	Solar and Wind energy Integrated with Transmission and Conventional sources
TANESCO	:	Tanzania Electricity Supply Company Limited
TOPSIS	:	Technique for Order Preference by Similarity to Ideal Solutions
TIAM-UCL	:	TIMES Integrated Assessment Model
TIMES	:	The Integrated MARKAL/EFOM System
TRNSYS	:	TRaNsient System Simulation
UCL	:	University College London
UCT	:	University of Cape Town
UETCL	:	Uganda Electricity Transmission Company Limited
UNDESA	:	United Nations, Department of Economic and Social Affairs, Population Division

UNIDO	:	United Nations Industrial Development Organisation
USD	:	United States Dollar
VIKOR	:	VIsekriterijumsko KOmpromisno Rangiranje
WSM	:	Weighted Sum Method

SYMBOLS AND ACRONYMS

AM	:	Autoregressive Model
ARAS	:	Additive Ratio Assessment method
BAU	:	Business As Usual
DSM	:	Demand Side Management
EFCS	:	Efficient Cooking Stoves
EL	:	Efficient Lighting
Eq.	:	Equation
Fbu	:	Franc Burundais “Burundian currency”
GHG	:	Greenhouse Gas
GJ	:	Gigajoule
GWh	:	Gigawatt-hour
kg	:	Kilogram
KSh	:	Kenyan Shilling
l	:	Liter
LIPS-OP/XP	:	Lahmeyer International Power System – Operation Planning / Expansion Planning
m^2	:	Meter square
MJ	:	Megajoule
MW	:	Megawatt
MWh	:	Megawatt-hour
NG	:	Natural Gas
NO_X	:	Nitrogen Oxides
PJ	:	Petajoule
RE	:	Renewable Energy

SO_2	:	Sulphur Dioxide
TJ	:	Terajoule
tmt	:	Thousand Metric Tonnes
VLCPDP	:	Vision 2030 + Least Cost Power Development Plan
W	:	Watt

DEFINITION OF TERMS

Activity Level	:	A measure of economic activity or social activity for which energy is consumed
Energy Balance	:	Summary resulting from energy production, conversion and consumption
Energy Intensity	:	Energy usage per device or per GDP “translating a measuring scale of inefficiency of energy of an economy”
GWP	:	This is a term used to appraise the contribution of GHG to global warming
Load shape	:	It is the net final fuel demand recording the variation of annual energy demand (for different devices) by season and time of day
Merit Order	:	This term defines the order in which a process is dispatched
Module	:	This is defined as branch that represents any sector of energy conversion (e.g. oil refining, generation of electricity, charcoal production, etc.).
Process	:	This term defines any individual technology converting one form of energy to another or a technology transmitting and distributing energy (e.g. oil combustion turbines, hydropower).
Reserves	:	This term defines the remaining quantity of fossil fuels (depletable fuels).
Time slices	:	These are meant to define the divisions of a season and time of day into which yearly loads (electric and others) are divided

Transformation : This term involves the process of energy conversion and transportation from point where primary resources are extracted and fuels imported to the point of consumption of final fuel.

CHAPTER ONE

INTRODUCTION

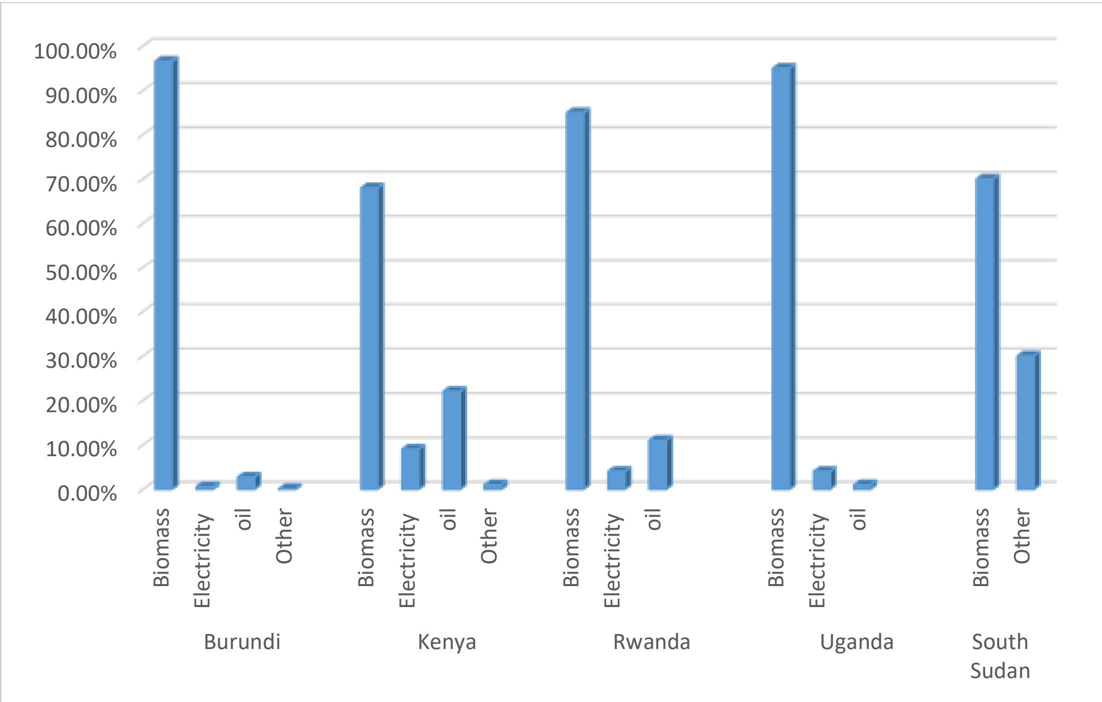
1.1 Background of the Study

Access to modern, affordable, reliable and sustainable energy for all is a basis for achieving other sustainable development goals (SDG – 7). However, this is far from being met in many African countries. It is expected that more than 640 million people in Africa will still rely on traditional biomass fuels for cooking by 2040 (Carvalho et al., 2019). In Sub-Saharan Africa, around 80 % of population are estimated to considerably rely on traditional biomass as cooking fuels; mainly charcoal, animal dung or agricultural residues (Dagnachew et al., 2019; Johnson et al., 2017). Furthermore, it is expected that the number of people with unimproved energy facilities (i.e. use of inefficient cooking stoves and traditional biomass) would increase through 2030 despite efforts that are being conjugated to increase electricity access rate (Morrissey, 2017).

The East Africa Community (EAC: Kenya, Tanzania, Uganda, Rwanda, Burundi and South Sudan) being part of Sub-Saharan region, is not an exception and faces these challenges of unimproved energy facilities. Despite some efforts to increase energy supply at national and regional levels in the region (Hafner et al., 2019), Burundi is still lagging from meeting its total power demand: only 10% of its population had access to electricity in 2012 (Ministry of Energy and Mining, 2012), this access rate has only turned to 11% in 2019 according to World Bank data. Nevertheless, Kenya has made a significant progress in terms of modern energy access (Manirambona et al., 2022).

Generally, the EAC countries still face challenges of universal energy access. A great portion of energy consumption in the region is traditional biomass. Burundi accounts about 96.6 % of total consumption in form of wood and charcoal whereas electricity, petroleum products and other are respectively represented by 0.6 %, 2.7 % and 0.1 %

(Sinzinkayo et al., 2015). The reliance on traditional use of biomass in Kenya is 68 % of its total energy consumption (Takase et al., 2021). The other countries in EAC also account high proportion of traditional use of biomass in their overall energy mix: Rwanda accounts 85 % (E. Hakizimana et al., 2020), Uganda 95% (Adeyemi & Asere, 2014), Tanzania 90 % (Felix & Gheewala, 2011) and South Sudan 70 % (Minister of Electricity and Dams, 2014). Figure 1.1 shows biomass energy consumption in total energy mix for EAC.



Source: Author's compilation from (Adeyemi & Asere, 2014; Felix & Gheewala, 2011; E. Hakizimana et al., 2020; Minister of Electricity and Dams, 2014; Sinzinkayo et al., 2015; Takase et al., 2021)

Figure 1.1: Biomass Energy Consumption in EAC Total Energy Mix

However, many driving factors are expected to influence future energy demand of the region, namely; high population growth rate; increasing housing demand, health and education; untapped minerals potential. Notably, Burundi has the second largest coltan reserve in the region and 6 % of world nickel reserves (African Development Bank, 2009, 2015).

However, due to a large gap in universal energy access in the EAC countries, the achievement of these objectives is still constrained. According to The World Bank data (2019), the national installed power capacity in each of the countries was still far from meeting the total energy demand for each country. In all these countries (expect Kenya), access to electricity was still below 50 % as of 2019. However, these countries have many options and resources for energy development. The hydropower potential capacity of the region is estimated to be more than 15 GW while solar insolation is more than 4 kWh/m^2.day, favorable for solar photovoltaic systems. Furthermore, the region is endowed with a huge potential of geothermal, peat, wind, natural gas (NG), oil and coal reserves which could be used for electrical production purpose (Hafner et al., 2019; Hakizimana et al., 2016; Ministry of Energy, 2018; Ministry of Energy and Mining, 2012, 2013; Mudaheranwa et al., 2019; Musonye et al., 2021; The Kenya Power and Lighting Company, 2019).

Despite many efforts being conjugated to meet the gap between energy supply and demand at national and regional level, significant efforts, however, will still be required to manage future scenarios for sustainable development. It is necessary to eliminate the deficit as soon as possible, but also go beyond just solving the deficit and make long-term energy planning for sustainable future development to ensure continuous economic growth.

In that regard, this study sought to support the EAC initiatives by planning and modelling pathways for its energy sustainability. It analyzed different available energy resources in the region, renewable and non-renewable, demand of energy in different sectors (residential, transport, industrial, agriculture and commercial, services and others), demography, market, urbanization development, economic development plans, as well as the development of renewable energies while taking into account energy policies. All these aspects require to follow a multi-criteria decision making “MCDM” and the Long-range Energy Alternative Planning (LEAP) model was used to create different scenarios and formulate policy recommendations which respond to the rising energy demand by 2040. The LEAP model was found suitable for this analysis as it is a demand driven tool able to integrate various drivers of energy demand such as GDP “ Gross Domestic Product ”, technological and population change; and other factors driving energy demand behavior such as end-use fuels, urbanization rate and fuels costs (Bhattacharyya & Timilsina, 2009). The countries energy demand and supply policies that include energy efficiency improvement and GHG “Greenhouse Gas” emissions mitigation were analyzed in this study. Simulations of direct emissions (at the point of emissions), measured at 100 – Year GWP “Global Warming Potential” were determined in CO_2 Equivalent emitted caused by energy consumption and transformation of different fuels (both renewable and fossil fuels) used in the countries. Kenya and Burundi were deeply analyzed as a model to be replicated in the other countries. The energy demand and supply were forecasted over 25 years of period, up to the year 2040 by considering 2015 as the base year and 2016 as the first simulation year.

The developed model would help EAC policymakers in energy resources planning and management by considering multiple criteria and scenarios.

1.2 Problem Statement

The EAC countries are all characterized by poor energy access. However, all these countries have a great potential for many energy alternatives development due their huge energy resources underexploited (Hafner et al., 2019). It is essential to diversify their respective energy sources to mitigate the gap between their growing energy supply-demand. Hence, the need to plan for their various available energy resources in their energy mix model in sustainable way.

While forecasting energy demand is the basis for sustainable energy development, systematic research on energy forecasting in Africa, particularly in East Africa, is still relatively rare (Han & Li, 2019).

Additionally, while the access to reliable modern energy services for all is still very low in all the EAC countries (EAC countries highly depend on traditional use of biomass), many driving factors will influence the future energy demand of the region: high population growth rate; building sector is in full expansion in order to address and solve the problems of housing, health and education; untapped mining potentials: e.g. Burundi has the second largest coltan reserve in the region and 6 % of world nickel reserves (African Development Bank, 2009, 2015) and many planned projects in Kenya (special economic zones, electrified standard gauge railway, mass rapid transit electrification, Konza techno city, Oil pipeline – LAPSSET “Lamu Port, South Sudan, Ethiopia Transport”, Integrated steel mills) which will require a much electricity (Government of Kenya, 2018). Thus, this pushes all the EAC countries to find solutions and try to search alternatives by improving their energy sector and diversifying energy sources.

However, electricity demand has been the only end-use energy considered in most of the different energy planning studies developed in the region. Although the countries energy policies have recently endeavored to increase RE share in order to face the growing energy demand (Fobi et al., 2018; Moner-Girona et al., 2019), their focus on techno-economic aspects may lead to non-sustainability. The public involvement is neglected in most developing countries when planning new energy projects (Oluoch et al., 2020). For instance, local population of Marsabit County in Kenya was found exposed to new conflicts caused by land and employment issues after a wind park of 310 MW was built in their region (Hardt, 2018).

The task of this study was therefore to sustainably model the future total energy demand of the region for possible energy management scenarios.

1.3 Objectives of the Research

1.3.1 General Objective

The aim of this study was to model the EAC energy sector pathways, long-term forecast and management scenarios for future energy balance and sustainable development of the region.

Kenya and Burundi were deeply analyzed in this study and the developed model would be duplicated in the other EAC countries.

1.3.2 Specific Objectives

This study has the following specific objectives to address:

i. To develop energy mix model while controlling the non-renewable energies;
ii. To analyze the current and future energy balance of the countries up to the year 2040;
iii. To appraise different energy policies of the countries to develop renewable energies and improve energy efficiency;
iv. To validate model in (iii) for long-term energy planning up to the year 2040.

1.4 Justification of the Study

Despite its huge energy resources not yet exploited (Hafner et al., 2019), the EAC region is still greatly characterized by poor energy access as shown by Figure 1.1. There is a need for the region to make robust sustainable planning studies in long term for its energy situation, by creating scenarios following different aspects and models to develop different energy options, improve energy efficiency and reduce greenhouse gas emission.

Hence, it is very challenging to achieve energy access for all without a proper planning that meets the goal of sustainable energy. Energy demand management is becoming an important issue since the future World is dependent on today's decision. Managing the energy resources in an optimal manner has become imperative among energy planners and policy makers.

1.5 Significance of the Study

The East African region expects a high growth in energy demand due to its high demographic and economic growth as well as increasing industrialization. In addition to these factors, lack of vigorous energy efficiency measures contributes to the rising of the countries' energy demand; hence, the need to integrate all these factors for a robust energy planning of the countries. Despite that the countries Governments recognize the importance of energy efficiency and improved cooking stoves through many previous published energy reports; the effect of these alternative energy policies was not quantified in the different studies.

Therefore, this study first provides the concept of prioritizing power technology options in the region using sustainable dimensions: Economic, Social, Environmental and Technical. This provides a critical policy contribution to the countries governments and energy projects investors by solving the dilemma of technologies prioritization for capacity expansion.

Secondarily, there was a need to develop robust energy planning policies in these countries for the development of the region; this by taking into account all energy fuels demanded by the residential and all economic sectors. Hence, this research sought to explore the effect of the policies in order to provide useful insights to the countries' policymakers.

The model developed in this study forecasts the total energy demand in all sectors and the effects of different policies on energy generation. This would provide insights on implementation of energy efficiency and conservation policies for highly consumed fuels and the model can be implemented in other countries of the Sub-Saharan countries with similar problems.

1.6 Research Questions and Conceptual Framework

The research questions of this study were as follow:

i. How sustainable are the potential power technology alternatives to be implemented in Kenya and Burundi?
ii. What will be the energy balance of the countries projected to the year 2040?
iii. What are the energy policies to be implemented in the countries to mitigate GHG emissions and reduce energy usage?
iv. How can the modelled results be validated in reference to real data?

These questions were developed to provide an output to the research consisting of modelling the East African energy sector towards sustainability. The study forecasts the energy balance of the two countries, Burundi and Kenya. Therefore, several methodologies were applied in the conceptual framework of the research. Figure 1.2 highlights the research conceptual framework applied to this Thesis.

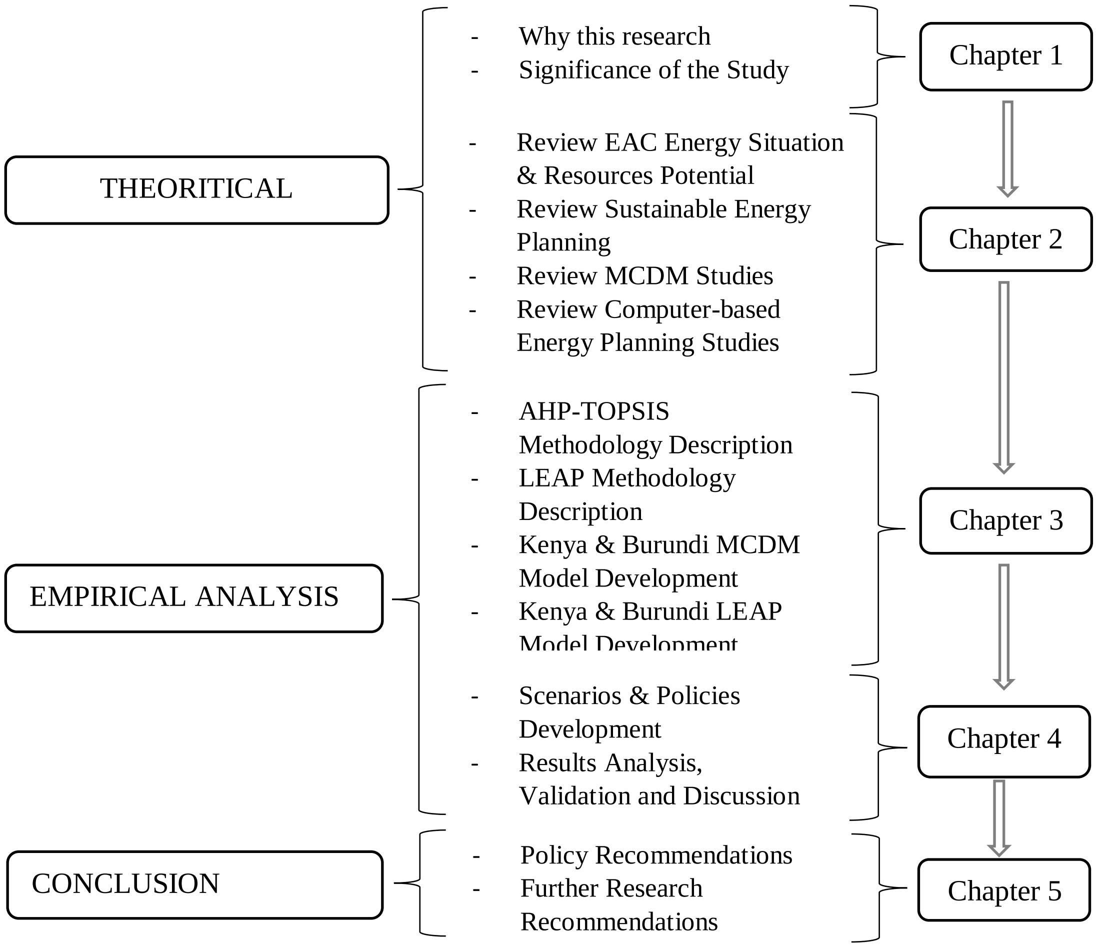


Figure 1.2: Research Conceptual Framework of the Thesis

The theoretical analysis responds to the need of conducting this research in EAC where an overview on the EAC energy situation and resources potential are given. Different energy planning tools are also reviewed for the MCDM and LEAP models in this stage; the hybrid AHP – TOPSIS and LEAP models are selected as suitable models to be applied in this study.

The empirical analysis provides the hybrid AHP – TOPSIS and LEAP models developments for Kenya and Burundi. Various polices and scenarios are also developed at this stage. This stage also provides the model validation by comparing real data and modelled results.

The last stage of the study gives summarized key findings of the research which involve the long-pathways energy strategies for the countries.

1.7 Structure of the Thesis

This thesis is organized into five chapters as follows:

Chapter 1 introduces the study where background on energy status of the EAC countries, objectives, research problem and significance of the study are presented. The thesis conceptual framework and its structure are also presented in this Chapter.

Chapter 2 presents the literature review related to energy planning and energy status in the EAC region. Various energy resources in the region (renewable and non-renewable) are analyzed. Furthermore, different tools used for sustainable energy planning are reviewed in this chapter. These tools are categorized according to their developer, tool name, model type and their application. Additionally, previous published research on various energy planning strategies for EAC are also reviewed in order evaluate the progress of each country. The published studies are organized by country, aim, model/tool used, findings and limitations. Initiatives and gap in EAC energy planning are discussed.

Chapter 3 gives a detailed method used to arrive to the intended objectives. The LEAP model and MCDM model are described in detail in this chapter. Required input data and systematic approach for the countries LEAP – MCDM is well described. Different energy policies on energy demand side management and on energy supply side to be implemented are also analyzed.

In Chapter 4, results from the simulations are given and discussed. Results for Kenya and Burundi are presented and discussed in detail.

Lastly, Chapter 5 concludes the findings and policy recommendations. Also included is the recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of EAC Energy Situation

The electrification rate in EAC countries is still low (as presented in Table 2.1) as of the year 2023. All the countries rely on traditional use of biomass for their overall energy consumptions (Figure 1.2). The estimated annual demand of biomass for cooking in Burundi was between 3.3 million to 4.5 million tonnes in 2013, which was greater than the national production (1.3 – 2.9 million of tones) (Ministry of Energy and Mining, 2013). With the national reserve estimated to be 200,000 ha in 2010 (Ministry of Energy and Mining, 2013), it makes it an unsustainable source in the long-term. The national power supply capacities are insufficient to meet the energy needs in each of the countries. Hence, the target of meeting a high rate of electrification cannot be achieved without a sustainable harnessing of the available energy resources.

However, the EAC countries are making progress with respect to tackling energy access challenges, including lack of electricity (Kenya reached 69.7 % of electricity access in 2019). Beside the common energy challenges faced in the region, such as unreliable electricity and reliance on traditional biomass several initiatives at the national and regional level, efforts are being conjugated by making some cooperation to address these challenges. For example, the inter-boundary projects with Burundi and DRC, 145 MW, at Ruzizi III, and with Burundi and Tanzania, 90 MW at Rusumo Falls.

Actually, Kenya as one of the country members of EAC is a developing country with a highest energy demand in this region. This country has huge potential of many energy resources not fully harnessed which include geothermal, wind, solar, coal and oil as presented in Table 2.1. The government of Kenya has a plan for its energy supply expansion which includes the coal-fired power plants in its energy mix model. Hence, there is a need to facilitate this country's energy expansion in sustainable perspectives. For the case of Burundi, the country has a lowest installed power capacity in the region despite having many reserves of energy resources not fully used including Solar, Hydropower, Biomass, Peat and Wind. Hence, a need for a sustainable planning for the countries' energy expansion model.

Table 2.1: Summary of the Status of EAC Power Sectors and Energy Resources Potentials

Country	Elect. Access(2019)*	Country's installed Capacity (Imports & shared excluded) (MW)			Energy Resources potential/reserves								
		Tot. (year)	Share		Hydro (GW)	Geother (GW)	Solar (kWh/m^2/d)	Wind (m/s)	Biomass	NG (bcm)	Oil (10^6barrels)	Coal	Peat
Kenya	69.7 %	2741 (2019)	Hydro Geother. Wind Biomass Solar Thermal	833.797 684 336.55 26 50.94 810.52	6	10	4 – 6	> 6	260 PJ	–	766	400million tons	–
Tanzania	37.7 %	1764 (2022)	Hydro Gas Wind Solar Biomass Thermal	581 876 2 2 63 240	4.7	0.65	4 – 7	5 – 9	530 PJ	1600	–	1.9bt	–
Uganda	41.3 %	1346.662 (2021)	Hydro Solar Biomass Thermal	1072.909 60.93 111.743 101.08	2.2	0.45	5 – 6	3.7 – 6	1650 MW	5	2590	–	800 MW
Rwanda	37.782 %	220.268 (2021)	Hydro Thermal Solar Methane Peat	104.628 58.8 12.05 29.79 15	0.3	0.17–0.34	4 – 6	2.36 – 2.97	–	55-60	–	–	1200 MW
Burundi	11.065 %	65.648 (2020)	Hydro Diesel	35.148 30.5	0.3	0.018	5.47	< 4.8	–	–	–	–	(47-58)*10^6 tons
South Sudan	6.721 %	80.4 (2016)	Foss. fuels RE	79.6 0.8	2.105	≅ 2.5	5 – 6	2.5		85	6000		

*The World Bank data (2019): Access to electricity (% of population)

Source: Author's compilation from (Avellino et al., 2018; CIA, 2022; Electricty Regulatory Authority, 2021; Eustache et al., 2019; Hafner et al., 2019; Mdee et al., 2018; Ministry of Energy, 2018; Ministry of Energy and Mining, 2012; Musonye et al., 2021; Nsabimana, 2020; Onyango et al., 2015; REEEP, 2012; Rwanda Energy Group, n.d., 2021; Sustainable Energy for All, 2013; The Kenya Power and Lighting Company, 2019; USAID, 2022; Whiting et al., 2015; Wilson, 2010)

2.2 Outlook of Sustainable Energy Planning

There is a big concern about pollution and energy demand around the World. In order to ensure a sustainable development, there is a need to consider energy technologies scenarios characterized by low environmental impacts (local, regional, global) and an equitable allocation of resources (UNDP, 2000). Additionally, many other factors are to be considered when dealing with energy planning with a sustainable development aspect. This involves the consideration of various factors such as technical, social, economic and environmental. Hence, it is crucial for decision makers to consider various criteria and objectives at different levels of electrification (Kumar, Sah, Singh, et al., 2017).

2.2.1 MCDM in Energy Planning and Recent Development

The concept of MCDM reflects numerous methods developed for helping decision makers in reaching better decisions (Løken, 2005). These methods have become popular for sustainable energy planning. For instance, an MCDM with 13 criteria enclosing economic, job market, quality of life of local populations, technical and environmental issues was used to assess future scenarios of Portugal power generation. This allowed to address the problem of long-term strategic power decision-making (Ribeiro et al., 2013).

Over the years, energy planning issues have been addressed using MCDM methods. Some examples, specifically for energy planning problems are described in Table 2.2.

Different stages applied in MCDM methods are (Fülöp, n.d.): 1. Define the problem; 2. Determine requirements; 3. Establish goals; 4. Identify alternatives; 5. Define criteria; 6. Select a decision making tool; 7. Evaluate alternatives against criteria; 8. Validate solutions against problem statement.

*Table **2.2**: Applications of MCDM Methods for Energy Planning Scenarios*

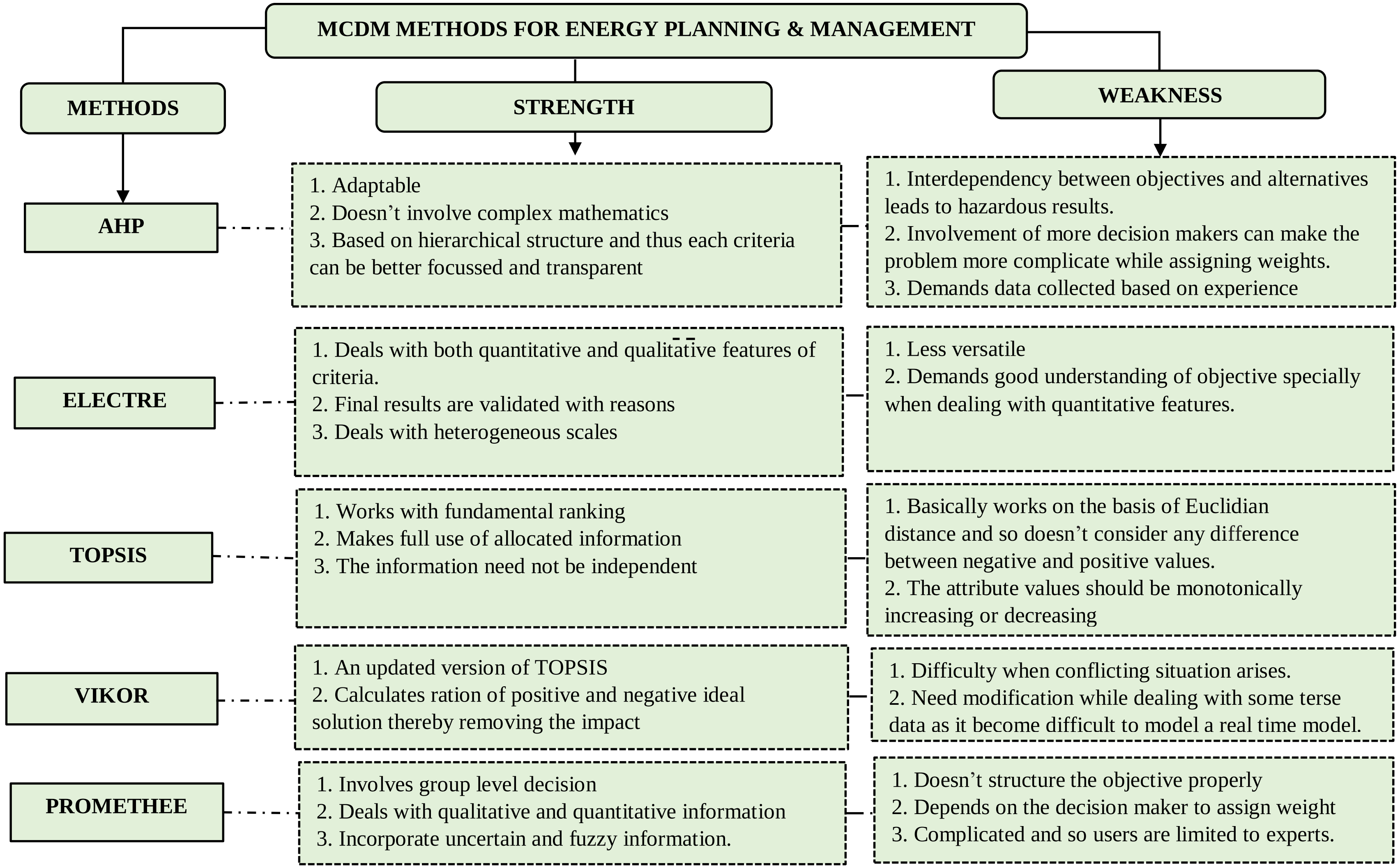
MCDM method	Year	Case study/Application
PROMETHEE "Preference Ranking Organisation Method for Enrichment Evaluations"	2010	Municipal area in Germany (Assess power generation technologies) (Oberschmidt et al., 2010); 2017/ Greek island (Assess future power generation options) (Strantzali et al., 2017); 2009/ island of Crete (Evaluate energy planning options) (Tsoutsos et al., 2009)
AHP "Analytical Hierarchy Process"	2021	Niger (Assess diverse power technologies) (Bhandari et al., 2021); 2018/Egypt (Assess power technologies) (Shaaban et al., 2018); 2017/Algeria (Rank RE technologies) (Haddah et al., 2017); 2013/Turkey (Select best RE technologies) (Demirtas, 2013); 2018/Nepal (Assess RE technologies) (Dhital et al., 2018); 2018/Turkey (Evaluate future relevant power technology portfolio) (Pasaoglu et al., 2018); 2011/Pakistan (Select a best option from different RE technologies) (Amer & Daim, 2011); 2015/Italy (Site selection**:** Analyze Solar PV systems) (Cucchiella & Adamo, 2015); 2017/Village in North East India (identify a suitable micro-grid) (Kumar, Sah, Deng, et al., 2017); 2015/Maharashtra-India (Performance evaluation of small hydropower projects) (Dinkar & D.V, 2015);
TOPSIS "Technique for Order Preference by Similarity to Ideal Solutions"	2014	Tunisia (Evaluate various electrification system strategies) (Brand & Missaoui, 2014);
VIKOR "VIsekriterijumsko KOmpromisno Rangiranje"	2015	Remote rural location in Venezuela (choose a best alternative for electrification) (Rojas-Zerpa & Yusta, 2015);
ELECTRE "Elimination and Choice Translating Reality"	2003	Sardinia region (Provide an action plan for RE deployment at regional scale) (Beccali et al., 2003);

2.2.2 Selection of MCDM Method

Varied application of MCDM methods influences a systematic approach when selecting a method to be used for a case study. Each method has its postulates and hypotheses (Guitouni & Martel, 1998). Some researchers have opted to combine many methods on a single study for results comparison. For instance, the ANP "Analytic Network

Process" was combined with multiple MCDM methods for a sustainable RE evaluation framework in China. The ranking results of WSM "Weighted Sum Method", TOPSIS, PREMETHEE, and ELECTRE were basically the same. Only the results of ELECTRE and VIKOR differed in some places (Li et al., 2020).

The AHP is one of the most commonly used methods of multi-criteria analysis (Stojanovic, 2013). Most popular MCDM methods were compared against four selected criteria "Measures to deal with uncertainty, User-friendliness and flexibility, Transparency and communication, Multi-stakeholder inclusion": AHP, DELTA and PROMETHEE II. As results, AHP method scored best with three "high" scores and one "medium" score, followed by the DELTA method with two "high" and two "medium" scores (Kurka & Blackwood, 2013). More than 90 published articles were reviewed to analyze the most popular method for a sustainable energy planning. AHP was found the most popular followed by PROMOTHEE and ELECTRE (Pohekar & Ramachandran, 2004). AHP was depended on to solve energy related issues (Amer & Daim, 2011; Bhandari et al., 2021; Rojas-Zerpa & Yusta, 2014; Ziuku et al., 2014). Figure 2.1 identifies some most used methods in energy planning and management and shows strength and weakness of each method.



Source: (Kumar, Sah, Singh, et al., 2017; Oberschmidt et al., 2010; Özcan & Çelebi, 2011)

*Figure **2.1**: Strengths and Weaknesses of most used MCDM Methods in Energy Planning and Management*

2.2.3 Computer-based Energy Planning Tools

Energy planning can be defined as a roadmap for meeting the energy needs of a nation and is accomplished by considering multiple factors such as technology, economy, environment, and the society that impact the national energy issues (Prasad et al., 2014). Despite the existence of different models for energy demand forecasting such as statistical and artificial intelligence, the computer-based models (bottom-up, top-down) provide proper accuracy and applicability.

Even though MCDM approach can help to identify an optimal energy mix for sustainable future power generation, it is important to evaluate how assessed resources would meet future energy demand. This can help decision makers for a strategic planning in power generation.

HOMER "Hybrid Optimization for Multiple Energy Resources" model has been the popular tool used in Sub-Saharan African in energy planning (Trotter et al., 2017) despite its limitation in time for not considering future scenarios. Notwithstanding, there are many computer based energy modelling tools used in energy planning (Mirjat et al., 2017; Prasad et al., 2014). The literature review shows different energy modelling tools which have been used for energy planning at various levels such as MARKAL "market and allocation" (Zonooz et al., 2009); ENPEP "Energy and Power Evaluation Program" (HAMILTON et al., 1990; Jaber et al., 2001); TIAM-UCL "TIMES Integrated Assessment Model" (Gadre & Anandarajah, 2019); LEAP "Long-range Energy Alternatives Planning" (Gresat et al., 2018; Ouedraogo, 2017b; Sadiq et al., 2013); MESSAGE "Model for Energy Supply Strategy Alternatives and their General Environmental Impact" (Kichonge et al., 2015); Network Planner (Ohiare, 2015); OSeMOSYS "Open Source energy Modelling System"; Power plan (Thiam et al., 2012); SimaPro (Günkaya et al., 2016); TRNSYS "TRaNsient System Simulation"

(Villa-arrieta & Sumper, 2018); GIS "Geographic Information Systems" (Mentis et al., 2015); Energy Plan (Hong et al., 2013; Østergaard, 2015). Table 2.3 provides a comparative assessment of some of the most used tools in energy planning.

Table 2.3: A Comparative Assessment of Some of the Most Used Tools in Energy Planning

Developer	Tool	Model type	Application	Reference
Aalborg University	EnergyPLAN	Bottom-up Simulation	Helps National/regional energy planning strategies by applying techno-economic analyses. Heat, electricity, transport and industrial sectors counted in.	(Giacomo et al., 2018; Hong et al., 2013; Lund et al., 2010; Østergaard, 2015)
ETSAP /IEA	MARKAL	Bottom-up; Investment optimization	Finds a cheapest energy system; cost-effective technique to limit emissions; Long-term analyses of energy balance for different scenarios	(Krzemien, 2013; Zonooz et al., 2009)
Argonne National Laboratory / IAEA	ENPEP-BALANCE	Bottom-up; Simulation	Macroeconomic analysis; energy demand forecast; integrated supply/demand analysis	(Brizard, 2015; HAMILTON et al., 1990; Jaber et al., 2001)
Stockholm Environment Institute	LEAP	Bottom-up; Optimization	Energy consumption, production and resource mining across all sectors: energy and non-energy sector greenhouse gas emission.	(Gresat et al., 2018; Ouedraogo, 2017b; Sadiq et al., 2013; Siteur & RWEDP, n.d.; Tait et al., n.d.)
National Renewable Energy Laboratory	HOMER	Bottom-up; Optimization	Evaluates different design options (off-grid connected and stand-alone) based on different RE energy sources	(Dawoud & Lin, 2015; Magni et al., 2020; E Manirambona et al., 2020; Ram & Thompson, 2016)
IAEA, UCL, UNIDO, KTH, UCT, Stanford, PSI, SEI, NCSU, others	OSeMOSYS	Optimization	Estimates lowest NPV cost for a given energy demand; counts the costs induced by each technology modelled; Evaluates the energy balance, accounting for emissions	(Gardumi et al., 2018; Howells et al., 2011; Lavigne, 2017; M Welsch et al., 2012; Manuel Welsch et al., 2014)

University of Wisconsin	TRNSYS	Simulation	Simulates all thermal and RE generation; nuclear, wave, tidal and hydropower excluded	(Entchev et al., 2013; Villa-arrieta & Sumper, 2018)
International Institute for Applied Systems Analysis	MESSAGE	Bottom-up; Investment optimization	Medium and long-term energy system planning, climate change policy analysis and scenario development for national or global regions	(Hakizimana et al., 2016; Kichonge et al., 2015; TOT, 2012)
Natural Resources Canada	RetScreen	Investment optimization	Evaluates energy production, lifecycle costs and GHG emissions reductions from RE	(Iqbal et al., 2014)
The Earth Institute in Columbia University	Network Planner	Scenario-based	Explore the costs of different electrification options in un-electrified locations	(Kemausuor et al., 2014; Ohiare, 2015)
Innovation Energie Developpement (IED), France	GEOSIM	Optimization	Focuses on rural electrification planning, used to identify grid extension and least cost of decentralized projects with RE resources.	(Kemausuor et al., 2020)
KTH-dESA	OnSSET	Optimization	Determines cheapest electrification technology option and required funds	(Isihak et al., 2022)
IEA/ ETSAP	TIMES	Bottom-up; Optimization	Techno-economic tool to represent technologies, fuels, emissions and their effect on all economic sectors	(Comodi et al., 2012; Pina et al., 2012)

IEA “International Energy Agency”; TIMES “The Integrated MARKAL/EFOM System”; OnSSET “Open Source Spatial Electrification Tool”; ETSAP “Energy Technology Systems Analysis Program”; dESA “Division of Energy Systems Analysis” PSI “Paul Scherrer Institute”; NCSU “North Carolina State University”; SEI “Stockholm Environment Institute” ; UCL “University College London” ; UCT “University of Cape Town”; UNIDO “United Nations Industrial Development Organization”

2.2.4 Energy Planning in East Africa

Researches concerning energy planning in Africa, particularly in East Africa, is scanty (Han & Li, 2019). The literature review on scholarly published articles shows that only Kenya has put more efforts in planning its energy sector than other EAC countries. Table 2.4 presents studies on energy planning in the six EAC countries and their findings.

Table 2.4: Literature Review on Applications of Various Energy Planning (at National Level) Models and Tools for EAC

Country	Aim	Model/Tool	Findings	Limitations	Ref.
Kenya	Present an improved grey Verhulst electrical load forecasting model	Improved grey Verhulst	The mean absolute percentage error were 7.82 % and 2.96 % for convectional grey Verhulst and the improved model respectively.	Seasonal variations "electioneering cycles, economic growth, oil prices fluctuations and (Eastern Africa) regional trade peace and stability" not considered.	(Mbae & Nwulu, 2020)
	Investigate pathways for 2030 Kenyan electrification targets	OnSSET/OSeMOSYS	Geothermal, Coal, Hydro and NG were found optimal energy mix for centralized national grid. High deployment of stand-alone systems is optimal in case of low demand scenario.	OSeMOSYS grid demand is underestimated; Time resolution in OnSSET assumes overnight electrification; Feed-in tariffs are not included in the analysis.	(Moksnes et al., 2020)
	Assess Kenyan energy system's GHG emission reduction targets under 3 demand levels (2020-2045)	TIMES	Energy security was to be achieved under two scenarios, and for all the three demand levels with a high dominance of RE in generation mix under carbon emission cap scenario compared to business as usual scenario	The study is restricted to the grid-connected supply; Some of the required data were not available at the time of the study	(Musonye et al., 2021)
	Explore pathways for Kenyan power sector under plausible scenarios (2020 -2035)	SWITCH	Geothermal was more sensitive to operational degradation than high capital costs; Storage, diesel engines, and transmission expansion enable up to 50 % of wind power penetration	Providing electricity to unconnected population not explicitly modelled; The model does not translate the progress results of KPLC (connections from 37 % in 2014 to 47 % in 2015) and does not include influence of air conditioning in households.	(Carvallo et al., 2017)
	Evaluate suitable expansion pathways for Kenyan power system for the period 2015 – 2020	LIPS-OP/XP	Electricity consumption anticipated to grow in medium-term by 7.2 % per year; Peak load expected to 40 % growth from 1,600 MW in 2015 to nearly 2,300 MW in 2020; Additional 4 million domestic connections needed during the study period; Electricity access was forecasted to 100 % in 2020	Very high uncertainty of demand ad of fuel price forecasts; The assessment relied on technical information from Client.	(Lahmeyer International, 2016)
	Assess transition paths to low-carbon electrical power generation for the period 2010 – 2040	LEAP	Total demand was forecasted to 57, 400 GWh by 2040 under Vision 2030 + Least Cost Power Development Plan (VLCPDP) and low-carbon scenarios; Total GHG emissions under SDGs and AU was 99.7 % and 97.6 % lower than	Off-grid electricity was not considered in the study; Demand side measures were beyond the scope of the study	(Kehbila et al., 2021)

			VLCPDP; RE share was 99 % under SDGs in 2040.		
	Assess features of daily energy consumption for 7 micro-grid locations in Kenya	PB /UB /First Order AM/AM - T/ AM - S/AM – S&T/ES	ES was found the best model compared to other models	Does not consider actual local weather conditions and information concerning main crops	(Otieno et al., 2018)
Tanzania	Address the affordability aspect and indicate how to equitably and fairly meet the SDG7	OnSSET	Equity method profits a higher percentage of population than equality method	The study does not consider stand-alone diesel systems and mini-grids in the subsidy analysis and does not incorporate more sophisticated justice methods	(Menghwani et al., 2020)
	Assess electricity supply options under the projected period (2010 – 2040)	MESSAGE	In 3 scenarios, total installed capacity forecasted to increase by 9.05 %, 8.46 % and 9.8 % respectively from a base value of 804.2 MW; Hydro, coal, NG and Geothermal were the least-cost supply options;	Air emissions control measures were not included in the model; The entire national electricity system was simplified to a single grid system;	(Kichonge et al., 2015)
	Analyze energy demand for all economic sectors (2010 – 2040)	MAED	Increased energy demand in biomass consuming sectors was a dominant energy form in service and household sectors.	The study does not perform a detailed analysis of supply side to optimize the use of resources locally available to lessen the reliance on biomass and imported energy.	(Kichonge et al., 2014)
	Implications of electricity sector expansion on Tanzanian sustainable development	OSeMOSYS	The electricity sector expansion was found to contribute to a high growth in carbon emissions.	The study does not differentiate energy consumption between urban and rural consumers, new accesses and reliability increases; Does not address the effect of different policies across other sectors of economy (e.g. energy efficiency).	(Rocco et al., 2020)
	Model alternative electrification pathways for Tanzania (2015 – 2040)	OSeMOSYS / GIS	New Policy scenario implies an investment of 25.3 billion USD; Universal access to energy was found to be achieved in 2030.	The relationship between GIS data and power system optimization is mediated by a first decisions made by a modeller; The model is restricted the study of new accesses to electricity.	(Rocco et al., 2021)
Uganda	Analyze monthly peak electricity demand from January 2008 to December 2013	ARIMA and ARCH/GARCH	A seasonal model ARIMA (0,0,0) (1,1,1) [12] gave better forecasts that show a continued increase in electricity demand for the coming months	Lack of precise data on other independent variables, such as weather changes and therefore the use of univariate time series	(Nakiyingi, 2016)

	Predict Uganda electricity consumption up to year 2040	PSO – ABC Algorithm	In 2040, the electricity consumption was found to be between [35,471.5, 36,317.6] GWh with an annual average increase of 10.1 – 11.3 %.	This study does not deal with forecasting where there is a rapid increase in electricity demand, it is mainly long-term forecasting	(Kasule & Ayan, 2019)
	Assess Electricity Demand Based on Population Spatial Distribution in Uganda	Land Scan algorithm	Additional generation capacity of 1.5 GW was to be availed to meet the lowest electricity demand scenario	The study does not distinguish urban and rural energy consumption patterns; Mathematical formulation without population distribution factor in Voronoi regions.	(Ajinjeru et al., 2017)
Rwanda	Analyze Rwanda's future energy system (2019 – 2050)	Energy PLAN	In 2050, an installed capacity of approximately 1,500 MW was found needed to meet a demand of 7 TWh for 100 % access to electricity	The study does not analyze possible flexibility in different energy demand sectors	(Mudaheranwa et al., 2019)
	Analyze future electricity supply-demand of Rwanda (2013 – 2045)	MESSAGE / MAED	Electricity demand was found to be 3361 GWh and 4940 GWh in 2045 for BAU scenario and high consumption respectively	The study does not consider any possible state subsidies	(Hakizimana et al., 2016)
Burundi	–	–	–	–	–
South Sudan	Select most suitable off-grid RE systems for both urban and rural regions	AHP / Super Decisions	Solar PV technologies found the best alternative for almost all locations; Hybrid systems with Diesel and/or Solar PV + storage was fond suitable for areas with Wind and Small hydropower resources.	The study is limited by lack of available and reliable data for measuring selection criteria	(Ayik et al., 2020)

SWITCH "Solar and Wind energy Integrated with Transmission and Conventional sources"; LIPS-OP/XP "Lahmeyer International Power System - Operation Planning / Expansion Planning"; PB "Persistence Benchmark"; UB "Unconditional Benchmark"; AM "Autoregressive model"; ES "Exponential Smoothing"; S&T "Seasonality and Trend"; MAED "Model for Analysis of Energy Demand"; ARIMA "Auto Regressive Integrated Moving Average"; ARCH "Auto Regressive Conditional Heteroskedasticity"; GARCH "Generalized Auto Regressive Conditional Heteroskedasticity"; PSO- ABC "Particle Swarm Optimization -Artificial Bee Colony"

2.2.5 Gap in EAC Energy Planning

The literature review on scholarly published works on various energy systems planning for EAC shows that, apart from Burundi, other countries have put efforts in planning for their energy sector (Table 2.4). However, most of the studies in the region considered associated factors (activity level and energy intensity) as deterministic values. Additionally, most of the previous studies in the region had only put more attention on electrical power such as generation capacity, capacity expansion and electricity demand (Ajinjeru et al., 2017; Ayik et al., 2020; Carvallo et al., 2017; Hakizimana et al., 2016; Kasule & Ayan, 2019; Kehbila et al., 2021; Lahmeyer International, 2016; Mbae & Nwulu, 2020; Moksnes et al., 2020; Mudaheranwa et al., 2019; Musonye et al., 2021; Nakiyingi, 2016; Otieno et al., 2018). This was also noticed by Ouedraogo , most of the studies on Africa are focused on electricity demand, for which data can be easily found (Ouedraogo, 2017a). Therefore, there is a need to develop a new and robust framework for energy demand and resources planning in these countries from a sustainable perspective and hence provide energy resources management scenarios.

Many previous energy sustainability assessment studies were carried out in different countries to facilitate energy decision makings (Ali Sadat et al., 2021; Amer & Daim, 2011; Ayik et al., 2020; Azerefegn et al., 2019; da Ponte et al., 2021; Elkadeem et al., 2021; Evans et al., 2009; Guleria & Bajaj, 2020; Haddah et al., 2017; Luo et al., 2020; Simsek et al., 2018; Strantzali et al., 2017; Strantzali & Aravossis, 2016; Troldborg et al., 2014; Tsoutsos et al., 2009; Vlachokostas et al., 2021; Zola et al., 2019). While fossil fuel-based power plants are still considered as options to be implemented in many countries (EAC countries included), many of the previous energy sustainability assessment studies did not consider all alternative energy resources in the evaluation;

most of them concentrated on assessing RE for energy generation (Amer & Daim, 2011; Ayik et al., 2020; Evans et al., 2009; Haddah et al., 2017; Strantzali & Aravossis, 2016; Troldborg et al., 2014; Tsoutsos et al., 2009), specific technologies options (Ali Sadat et al., 2021; Bhandari et al., 2021; da Ponte et al., 2021; Simsek et al., 2018; Strantzali et al., 2017; Vlachokostas et al., 2021; Zola et al., 2019) and RE site selection (Elkadeem et al., 2021; Guleria & Bajaj, 2020; Luo et al., 2020).

Although fossil fuels are the main sources of pollution and greenhouse gas emissions, they still present some advantages such as being the cheapest option for electricity generation in many countries. Nevertheless, these sources are challenged by their limited resource potentials in future and are expected to be depleted. On the other hand, RE technologies being the key to green and secure energy in the future, they still have some obstacles such as the low ability to respond to peak-load and some technologies are still very expensive to be exploited. Therefore, due to these barriers/opportunities in exploiting energy resources, this study sought to consider the diversification of all available energy resources in view of sustainability.

In EAC, while many previous studies were conducted in Kenya to evaluate Kenyan energy planning scenarios, there is still lack of energy planning studies for the case of Burundi. Interestingly, most of the studies on country have analyzed the technical aspect such as dynamic power consumption (Fobi et al., 2018) and demand forecasting (Lahmeyer International, 2016; Mbae & Nwulu, 2020; Otieno et al., 2018), the techno-environmental aspect such as low carbon capacity expansion (Carvallo et al., 2017; Kehbila et al., 2021), the techno-economic electricity expansion aspect (Moksnes et al., 2020; Moner-Girona et al., 2019) and economic, techno-environmental electricity expansion aspect (Musonye et al., 2021).

Furthermore, previous studies have also analysed the Kenyan power system using varied methods. Kenya's electrification strategies were investigated targeting the year 2030 (Moksnes et al., 2020). The investigation relied on a combination of the tools OnSSET/OSeMOSYS "Open Source Spatial Electrification Tool/Open Source energy Modelling System" and fossil fuels, mainly coal and natural gas, were found much important for the optimum Kenyan energy mix system. Musonye et al. evaluated greenhouse gas emissions reduction of the Kenyan energy system using TIMES "The Integrated MARKAL/EFOM System" (Musonye et al., 2021). By using SWITH "Solar and Wind energy Integrated with Transmission and Conventional sources", the Kenyan power system was analysed in different paths under diverse scenarios (Carvallo et al., 2017). Lahmeyer International used a combination of LIPS–OP/XP "Lahmeyer International Power System–Operation Planning / Expansion Planning" to explore suitable pathways to expand the Kenyan power system from 2015 to 2020 (Lahmeyer International, 2016). By using LEAP "Long–range Energy Alternatives Planning", different pathways of decarbonization strategies of the Kenyan power system were analysed for the period 2010 – 2040 (Kehbila et al., 2021). However, to the authors' knowledge, no previous study addressed the concern of evaluating all the potential Kenyan power options against sustainability dimensions as a whole since selecting power technology options has become a multidimensional problem (Strantzali et al., 2017). The MCDM methods have not been applied in this context for the Kenyan case. Consequently, there is a need to conduct an analysis considering different assessment criteria. The application of MCDM methods is an interesting tool able to bring together several variables in order to handle a decision-making problem.

Therefore, the use of MCDM was recommended in order to consider all sustainable dimensions in energy planning. Although the MCDM helps to identify optimal energy mix for sustainable future power generation, there is a need to assess evaluated resources would meet future energy demand for a strategic planning of energy generation. The Long-range Energy Alternatives Planning (LEAP) model was found to be an interesting tool due to its suitability to model total future energy demand especially where data would be a limitation as found for EAC countries.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This section describes the methodology used for the application of MCDM and LEAP models for EAC countries. Type of data collected and data collection methods are also described. Kenya and Burundi served as reference countries that were deeply explored.

3.2 Study Area Description and Data Collection

3.2.1 Study Area Description

This research intended to model the East African Community energy sector towards sustainability. As of 2021, the countries constituting this community were six (Burundi, Kenya, Uganda, Tanzania, Rwanda and South Sudan). However, due to time and budget constraints, it was not possible to model all the countries. Therefore, two factors were considered in choosing representative countries: characterized with low and high energy planning studies; and those with low and high usage of traditional biomass fuels in their total final energy consumption.

Figure 3.1 shows the map of the countries constituting the East African Community as of 2021.

Source: (EAC, 2021a)

Figure 3.1: East African Community Member Countries as of 2021

Therefore, Kenya was chosen as pioneer country in terms of energy planning studies and low percentage of dependence on traditional biomass fuels in its total energy consumption (as compared to other EAC countries) while Burundi was selected for its low energy planning studies and high percentage of reliance on traditional biomass fuels in its total energy consumption, as compared to other EAC countries (Manirambona et al., 2022).

The analysis from the two countries was to provide a model that can be replicated in the other EAC countries as they seemed to share similar energy access challenges despite a certain significant progress in some of the countries.

3.2.2 Data Type and Collection Methods

In order to apply the MCDM method, primary and secondary data were utilized. Primary data were collected through a survey-questionnaire designed for energy experts in the countries (Appendix 2). Regarding the minimum or maximum number of experts to be involved when collecting these data and views, different studies used various number of participants to accomplish their research results. For instance, by using Fuzzy AHP method, Sadat et al. relied on ninety-one respondents (Ali Sadat et al., 2021). Elkadeem et al. depended on seven energy experts for pairwise comparison of sustainability indicators (Elkadeem et al., 2021) while Garni at al. relied on twenty experts' opinions in their survey regarding the MCDM process (Al Garni et al., 2016).

Therefore, non-probability sampling technique was applied in this research where expert knowledge from participants was needed and the purpose was not to test a hypothesis.

Hence, researchers and other energy experts in energy sectors were respondents in this survey. A random selection of energy experts from various institutes were targeted. In Kenya, due to availability of many energy institutes, it was easy to find respondents as compared to the Burundi case. 40 respondents were involved in this survey for the Kenyan case and 10 for the case of Burundi. These respondents were energy specialists (researchers in energy studies and professionals in energy sector). For Kenya, the respondents were 10 researchers in energy field (5 from Moi University and 5 from University of Nairobi), 30 experts in energy sector (10 from Ministry of Energy; 10 from Kenya Power and Lighting Company – KPLC and 10 from Rural Electrification Authority – REA). For the case of Burundi, the respondents were 4 researchers in energy field (2 from the University of Burundi and 2 from the school ENS), 6 experts in energy sector (2 from Ministry of Energy and Mines; 2 from the national utility – REGIDESO and 2 from Burundian Agency for Rural Electrification – ABER).

For the application of the LEAP model, secondary data was collected from different sources: local utilities in the countries such as REGIDESO for Burundi, KPLC for Kenya and various published reports through a systematic review.

3.3 Energy Resources Assessment and Ranking of Different Energy Supply Options

The problem and decision-making tool being defined in the introduction and literature review sections, the other steps of MCDM are presented in this methodology section.

Therefore, this section of the Thesis aimed at developing a model for a sustainable prioritization of different energy alternatives for EAC countries with a deep analysis on Kenya and Burundi.

3.3.1 Selection of Energy Generation Alternatives

This study built its selection on the energy resources potential in each country as well as on governments willing to integrate them in their future energy generation.

Therefore, Kenya presented eight technologies which were Hydropower, Geothermal power, Biomass power, Wind power, Solar PV, Concentrated Solar Power (CSP), Coal and Oil-fired power plants. The coal-fuelled power plant was not a technology under operation as of 2022 in Kenya, but it was included in the different alternatives for the reason that the Kenyan government had already showed interest in this project. For instance, the first coal-fired power plant project of 960 MW using imported coal was expected to be operational in 2024 (Ministry of Energy, 2018). For the case of Burundi, only seven alternatives were possible: Hydropower, Geothermal power, Biomass power, Wind power, Solar PV, CSP and Peat fired power plants. The peat was introduced as Burundi had shown interest in exploiting this resource for power generation purposes, demonstrated by its initial plan to construct a 15 MW peat power plant which was expected to be financed through public-private partnership with BUCECO company and commissioned in 2020 (Nsabimana, 2020).

3.3.2 Establishment of Criteria and Sub-criteria

The IAEA "International Atomic Energy Agency" worked together with the IEA "International Energy Agency" and other international organizations, for the purpose of sustainable development to provide a set of 30 energy indicators focusing on social, environmental and economic dimensions (IAEA, 2005). However, many researches have been relying on opinion from their country's experts for the analysis and validation of sustainable indicators to be used depending on energy project type. For instance, Brand and Missaoui used 13 indicators validated by experts in their country when assessing different scenarios for Tunisian electricity mix (Brand & Missaoui, 2014). In the same way, future scenarios of Portuguese power generation was evaluated using 13 indicators after experts consultation (Ribeiro et al., 2013). In analysing the sustainability of future electrification options of a Greek Island, Strantzali et al. opted for 7 indicators (Strantzali et al., 2017). A rural electrification project was planned with the help of MCDM using 13 indicators for sustainable option selection (Rojas-Zerpa & Yusta, 2015).

Similarly, in order in to use available energy resources in the EAC countries in a sustainable way, energy experts were involved. A list of 20 indicators were selected and analyzed in accordance to literature review on most used indicators for energy alternatives assessment (Brand & Missaoui, 2014; Liu, 2014; Ribeiro et al., 2013; Shaaban et al., 2018; Strantzali et al., 2017). This list was presented to the energy experts for validation. Hence, 17 indicators (interchangeably referred as sub-criteria in this study) were agreed and used for this study. The selection made included some of the eight major indicators, namely: efficiency, installed capacity, investment cost, O&M cost, CO_2 emissions, land use, job creation and social acceptability as highlighted in the review of (Strantzali & Aravossis, 2016) for energy planning projects.

Although sustainable development indicators (SDI) are grouped into three dimensions, Social, Economic and Environment (Vera & Langlois, 2007), many researchers used additional dimensions based on their study context. However, most of the sustainable indicators for assessing power technologies can be classified into four groups "interchangeably referred as criteria in this study" (Strantzali & Aravossis, 2016). As such, four criteria were used for the evaluation in this present study: economic, technical, environmental and social. The technical dimension was added as it was found to have a growing consideration in recent researches on energy sustainability (Amer & Daim, 2011; Liu, 2014; Rojas-Zerpa & Yusta, 2015; Shaaban et al., 2018; Strantzali et al., 2017; Strantzali & Aravossis, 2016).

Hence, 17 sub-criteria were used to evaluate the different technologies. Table 3.1 shows the criteria with their associated sub-criteria selected. The sustainability targets are indicated by "+" (more is better) and by "–" (less is better).

Table 3.1: Criteria and Sub-criteria Determination

Criteria	Sub-criteria	Code	Unit	Benefit attribute
Economic: C_1	Capital cost	C_{11}	USD/kW	-
	Fix. O&M cost	C_{12}	USD/kW-yr	-
	Var. O&M cost	C_{13}	USD/MWh	-
Technical: C_2	Reliability	C_{21}	–	+
	Capacity factor	C_{22}	%	+
	Technology maturity	C_{23}	–	+
	Resource availability	C_{24}	TWh/year	+
	Ability to respond to peak load	C_{25}	–	+
Environmental: C_3	Land requirement	C_{31}	m^2/kW	-
	CO_2 emissions	C_{32}	g/kWh	-
	NOx emissions	C_{33}	g/kWh	-
	SO_2 emissions	C_{34}	g/kWh	-
	CH_4 emissions	C_{35}	g/GJ	-
	Water consumption	C_{36}	kg/kWh	-
Social: C_4	Job creation	C_{41}	Total job-years/GWh	+
	Safety risks	C_{42}	Fatalities/GWeyr	-
	Social acceptability	C_{43}	%	+

3.3.3 Indicators Analysis: Sub-criteria Evaluation

The data for the indicators used were obtained from the published reports by international organizations (IRENA), local publications (Ministry of Energy) and other similar previous conducted studies in other countries. Crystalline solar PV modules for PV plants (utility scale), solar thermal tower with storage, Gas combined cycle (new built) and coal (new built), Diesel reciprocating engine generators for oil-fired power plants and onshore wind were assumed in this study.

3.3.3.1 Technical Indicators

- *Reliability:*

The reliability implies the probability for a system to perform appropriately for a precise time duration without any repair during its operation (Z. Biserčić & S. Bugarić, 2021). This indicator is often considered as qualitative parameter (Beccali et al., 2003). Its evaluation was based on data obtained from (Bhandari et al., 2021; Troldborg et al., 2014). The different technologies and their reliability values are highlighted in Table 3.2.

Table 3.2: Technical Indicators

Alternative	Reliability Qual. [1, 5]	Capacity factor (%)	Technology maturity Qual. [1, 5]	Resource availability (TWh/year)		Ability to respond to peak load Qual. [- 2, + 2]
				Kenya	Burundi	
Hydro	4	25 – 80	5	25	5	+ 2
PV	2	21 – 34	4	23000	888	- 1
CSP	2	39 – 68	3	15400	786	+ 1
Wind	4	38 – 55	5	1800	12.1	- 1
Geother.	5	80 – 90	4	87.6	0.158	+ 1
Biomass	4	80 – 85	4	3.61	$5.96*10^{-11}$	0
NG	-	50 –70	5	0	0	+ 2
Oil	4	10 – 95	5	65.09	0	+ 2
Coal	4	63 – 83	3	162.82	0	0
Peat	4	91	2	0	0.055	0

Note: Qual. – Qualitative

- *Capacity factor:*

This parameter, expressed in percentage (%), was obtained from (IRENA, 2015) for hydropower; (IRENA, 2012b; Lazard, 2017) for Biomass and Oil; (Lazard, 2020) for PV, CSP, Wind, Geothermal, NG and Coal power plants; (J. de D. K. Hakizimana et al., 2016) for Peat. The values of capacity factor of the technologies under investigation are shown in Table 3.2.

- *Technology maturity:*

This indicator is very important in the planning process. It is a qualitative indicator and reveals a state-of-art of a given energy technology. Hence, scale points from "1" (low technology maturity, i.e. only laboratory tested) to "5" (highest technology maturity, i.e. commercially available with high market penetration) were used for its assessment. The scale points were considered based on literature review on various previous studies (Beccali et al., 2003; Troldborg et al., 2014; Tsoutsos et al., 2009) where this indicator was addressed. Data for technology maturity were considered based on the research of (Troldborg et al., 2014), (Held et al., 2017) and (Alabbasi et al., 2022). According to Alabbasi et al., Wind is high mature technology, PV a mature and CSP a least mature technology (Alabbasi et al., 2022). Additionally, the study of Doukas et al. (Doukas et al., 2007) revealed that Coal is a less mature technology than Biomass while Natural Gas is the highest. Table 3.2 includes the technology maturity for different technologies.

- *Resource availability:*

This is a key parameter in this study. The different alternatives were chosen based on energy resources potential in the region. The data for in TWh-yr for Hydro, PV, CSP was obtained from (Hafner et al., 2019) for Kenya and Burundi. Wind potential was also obtained from (Hafner et al., 2019) for Kenya. The wind velocity in Burundi is below 4.8 m/s (Ministry of Energy and Mining, 2012). The wind potential for Burundi is estimated to be 15.2 TWh/yr (if no-grid restriction), 12.1 TWh/yr (with grid restriction) and 0.0 TWh/yr (Capacity factor – CF > 20 %) (UNEP, n.d.). It should be noted that this data represent techno-economical feasible energy potential. Some data were not found TWh/year and conversion was made by assuming the reserves for coal, oil, gas and peat will be used up to 2040 and no additional reserves will be found in future. The estimated 10 GW (Hafner et al., 2019; Ministry of Energy, 2018) and 0.018 GW (Hafner et al., 2019) of geothermal potential for Kenya and Burundi respectively were converted in TWh-yr; the 260 PJ biomass potential for Kenya (Hafner et al., 2019) were converted in TWh-yr; the estimated 0.77 billion barrels of oil reserves for Kenya (Hafner et al., 2019) were converted in TWh-yr (1 million barrels of oil equivalent = 1.7 TWh); The estimated discovered 400 million tons of coal reserves for Kenya (Ministry of Energy, 2018) were converted in TWh-yr (1 million tons of coal equivalent = 8.4 TWh); the estimated 58 million tons of peat reserves for Burundi (Ministry of Energy and Mining, 2012) were converted in TWh-yr considering a calorific value of 14.7 MJ/kg (Manirakiza et al., 2020); the biomass potential (agricultural waste) in Burundi estimated at 76924 tons/year (Manigomba et al., 2019) was converted to TWh-yr considering average calorific value of agricultural wastes of 1500 cal/kg (Awulu et al., 2018).

The energy resources potentials for Kenya and Burundi expressed in TWh/year are presented in Table 3.2.

- *Ability to respond to peak load:*

This is a qualitative indicator. The ability to respond to peak load is high for Natural Gas and Oil-fired power plants. For base-load power plants (Coal and Nuclear) their ability is low compared to the previous power plants and higher than intermittent RE

(PV, Wind). Therefore, this indicator was evaluated using scale points between "- 2" (low ability" and "+ 2" (high ability) based on data suggested in (Brand & Missaoui, 2014). Hydropower was considered to be of high ability due to its fast startup time and hydropower plants with reservoir was assumed. Values for this indicator are presented in Table 3.2.

3.3.3.2 Economic Indicators

- *Capital Cost:*

Access to investments is one of the barriers for energy projects implementation in African countries (Muzenda, 2009). Therefore, the capital cost needed to construct 1 kW for the different power technologies was used in this evaluation. Lazard analysis for total capital cost (USD/kW) for PV, CSP, Wind, Geothermal, NG and Coal power plants (Lazard, 2020) was used. The data for hydropower and peat were obtained from (IRENA, 2015) and (J. de D. K. Hakizimana et al., 2016) respectively while data for Biomass and Oil were found in (Lazard, 2017). These data are presented in Table 3.3.

Table 3.3: Economic Indicators

Alternative	Capital cost (USD/kW)	Fixed O&M cost (USD/kW-yr)	Var. O&M cost (USD/MWh)
Hydro	450 – 3500	20 – 60	2.00
PV	825 – 975	9.50 – 13.50	-
CSP	6000 – 9090	75.00 – 80.00	-
Wind	1050 – 1450	27.00 – 39.50	-
Geothermal	4500 – 6050	13.00 – 14.00	9.00 – 24.00
Biomass	1700 – 4000	50.00	10.00
NG	700 – 1250	14.50 – 18.50	2.75 – 5.00
Oil	500 – 800	10.00	10.00
Coal	2900 – 6225	39.75 – 83.00	2.75 – 5.00
Peat	2010	23	4.00

- *O&M (Operation and Maintenance) Cost:*

The fixed O&M (USD/kW-yr) and variable O&M (USD/MWh) costs were considered in this study. Data were obtained from analysis of Lazard for PV, CSP, Wind, Geothermal, NG and Coal (Lazard, 2020). For hydropower (IRENA, 2015), Biomass (Lazard, 2017) and Peat (Hakizimana et al., 2016). The different data are shown in Table 3.3.

3.3.3.3 Environnemental Indicators

- *Land Requirement:*

The land requirement for power plants is always a big concern. In this study, the data suggested by (Chatzimouratidis & Pilavachi, 2008) was used for Hydro, PV, Wind, Geothermal, Biomass NG, Oil, Coal. Data for CSP was obtained from (Troldborg et al., 2014). Due to lack of data, Peat was supposed to have the same land requirement as coal-fired power plant. Data for land requirement for the different technologies are shown in Table 3.4.

Table 3.4: Environmental Indicators

Alternative	Land requirement (m^2/kW)	CO_2 (g/kWh)	NO_X (g/kWh)	SO_2 (g/kWh)	CH4 (g/GJ)	Water consumption (kg/kWh)
Hydro	750	2 – 20	0.004 – 0.06	0.001 – 0.03	-	65 – 70
PV	35	49.174	0.178	0.257	-	1
CSP	40	13 –19	0.054 – 0.082	0.035 – 0.049	-	3.02
Wind	100	3 – 41	0.02 – 0.11	0.02 – 0.09	-	0
Geother.	18	18.913	0.28	0.02	-	12 – 300
Biomass	5000	8.5 – 130	0.08 – 1.7	0.03 – 0.94	40	18.5 – 250
NG	2.5	380 – 1000	0.2 – 3.8	0.01 – 0.32	3	78
Oil	2.5	530 – 900	0.5 – 1.5	0.85 – 8	8	78
Coal	2.5	660 – 1050	0.3 – 3.9	0.03 – 6.7	5.5	78
Peat	2.5	1120	0.576	0.273	4.5	78

- *CO_2, NO_X, SO_2 and CH_4 Emissions:*

When the resources are used for electric power generation, they are subject to pollution. The life-cycle emission from these alternative technologies was obtained from (Kuo & Pan, 2018; Steen, 2001) for coal, NG, Oil, Biomass, Wind and Hydropower; from (Chatzimouratidis & Pilavachi, 2008) for PV, and geothermal; and from (Peter

Viebahn, Stefan Kronshage, Franz Trieb (DLR), 2008) for CSP. The life cycle pollution for peat used for electricity production was taken from (Häsänen et al., 1986; Murphy et al., 2015). Data for emissions from the different technologies are shown in Table 3.4.

- *Water Consumption:*

Water is consumed during different phases of lifecycle of a power plant and water demand by energy sector is an emerging problem (Colmenar-Santos et al., 2014; Onat & Bayar, 2010). Hence, it is an important parameter in this case study, especially for Kenya which is known to be a dry country and among countries with significant water stress (Marshall, 2011). The water consumed during operation of power plants was the main focus in this study. This mainly refers to the quantity of water consumed in cooling systems (e.g.: Fossil fuels, Nuclear, CSP, Geothermal and Biomass power plants), cleaning process (Solar PV and CSP) and water losses by evaporation (Hydropower). Different values were obtained from (Evans et al., 2009; Onat & Bayar, 2010) for PV, Wind, Hydropower, Geothermal and Coal; from (Colmenar-Santos et al., 2014) for CSP; and (Rovere et al., 2010) for Biomass (based on Bagasse). The water consumption in operation of wind power plants is almost 0 kg/kWh (Rovere et al., 2010) while solar PV consumes little amount (less than 1 kg/kWh) (Onat & Bayar, 2010) in cleaning process. Data for water consumption for the different technologies are shown in Table 3.4.

3.3.3.4 Social Indicators

- *Job Creation:*

The job creation refers to lifetime of the technologies which include manufacturing, construction, installation and O&M/fuel processing. Data for the different technologies were obtained from (Bacon & Kojima, 2011; Wei et al., 2010) based on direct generated jobs/GWh. Oil and NG were supposed to have a same employment factor

(Rutovitz et al., 2015). The data for peat was assumed to have a same employment impact as for coal. The indicators for the different technologies are presented in Table 3.5.

Table 3.5: Social Indicators

Alternative	Job creation (Total job-years/GWh)	Safety risks (Fatalities/GW_eyr)	Social acceptability
Hydro	0.27	0.945	68 %
PV	0.87	0.000245	94 %
CSP	0.23	0.000245	94 %
Wind	0.17	0.00189	69 %
Geothermal	0.25	0.00174	56 %
Biomass	0.21	0.0149	56 %
NG	0.11	0.202	–
Oil	0.11	1.69	30 %
Coal	0.11	1.08	32 %
Peat	0.11	1.08	32 %

- *Safety Risks:*

Risk indicator is an important factor that contributes to decision making when formulating energy policies. These parameters expressed in form of fatality rate (Fatalities/GW_eyr) were taken from (Burgherr et al., 2011) for the different technologies. No data was found for CSP technology from literature review. Hence, fatalities caused by lifecycle solar PV power plants were assumed for CSP. Similarly, peat and coal fired power plants were supposed to have same fatalities effect. The data for fatalities caused by the different technologies are shown in Table 3.5.

- *Social Acceptability:*

This parameter is a qualitative indicator, assessed through consultation with local community for their views. Some previous studies used qualitative scale for social acceptance evaluation (Brand & Missaoui, 2014; Troldborg et al., 2014). For the case of this study, results (in percentage) from a nationwide survey conducted by Oluoch et al. in Kenya (Oluoch et al., 2020) was used. Values for public positive attitudes towards different energy technologies from that survey's feedback were used in this study. The values for the social acceptability (presented in %) for the different technologies are presented in Table 3.5.

3.3.4 Ranking of Different Energy Supply Options: Hybrid AHP/TOPSIS Model

This study evaluated all the energy resources in the countries by using multi-criteria decision-making approach. Four criteria were considered: technical, social, economic and environmental. A hybrid AHP/TOPSIS was used to the alternative power technologies, targeting the roadmap 2040.

3.3.4.1 Weights of Criteria and Sub-criteria

The AHP method was used to determine the weights for criteria considered. The weights of criteria and sub-criteria were evaluated in a pair-wise comparison using scoring scale of Saaty (Saaty, 1987) as shown in Table 3.6. Their importance were regarded to power technology selection according to feedback from participants (energy experts at country level) in questionnaire that was designed for this purpose.

Table 3.6: Scoring Scale of Relative Priorities

Scale	Degree of Preference
1	Same significance
3	Weak significance
5	Strong significance
7	Very strong significance
9	Extreme importance
2, 4, 6, 8	Intermediate value

Source: (Saaty, 1987)

Therefore, the weights were determined by AHP method as follows:

Step 1- Comparison matrix establishment*:* This matrix is made of results of pairwise comparisons from the distributed questionnaires. This comparison reflects how two elements (criteria or sub-criteria) with a common parent in the hierarchy relate to each other (i.e. element "*a*" is extremely important to element "*b*").

Step 2- Weights determination*:* After a comparison matrix is established, a weighting vector of "k" element is calculated by Eq. 0.1:

$$w_k = \frac{1}{n}\sum_{j=1}^{n}\left(a_{kj} \Big/ \sum_{i=1}^{n} a_{ij} \right) \qquad (k = 1,\dots\dots\dots, n) \qquad (3.1)$$

Where *i*, *j* and *n (n = m×p if i=1, …., m and j=1,….; p*) are respectively row, column and dimension of the comparison matrix and a_{ij} is the matrix element of row *i* and column *j*.

Steep 3- Consistency Check: The comparison matrix obtained is reasonable in case there is consistency (Ishizaka & Labib, 2009; Saaty, 1987; Stojanovic, 2013). Hence, a consistency index (*CI*) is given by Eq. 0.2.

$$CI = (\lambda_{\max} - n) \Big/ (n-1) \qquad (3.2)$$

Where $\lambda_{\max}$ is is maximal eigenvalue.

Then, the consistency ratio CR is obtained by applying Eq. 0.3.

$$CR = CI \Big/ RI \qquad (3.3)$$

Where RI is called random index.

Table 3.7 shows calculated Consistency ratio values RI for different matrix dimensions.

Table 3.7: Saaty RI Values

sMatrix order-n	1	2	3	4	5	6	7	8	9	10
RI	00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: (Saaty, 1987)

Hence, the matrix is called consistent if *CR ≤10 %* (Ishizaka & Labib, 2009; Saaty, 1987; Stojanovic, 2013).

Therefore, the problem can be modelled using the structure shown by Figure 3.2.

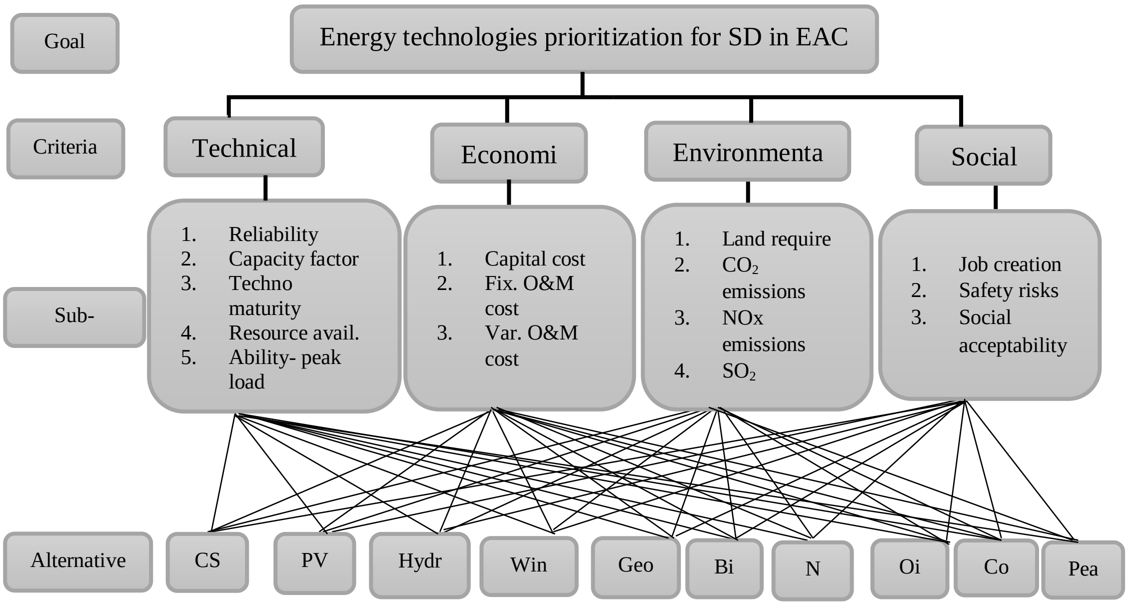


Figure 3.2: Flowchart of Energy Alternatives Technologies Ranking in EAC

3.3.4.2 Ranking of Energy Alternatives

After the weights were determined by the AHP method, the TOPSIS was used to rank different technologies. Figure 3.3 shows the flowchart of the hybrid AHP - TOPSIS method used. A detailed methodology of TOPSIS can be found in (Roszkowska, 2011). The model is conducted as described below.

After "*m*" alternatives, "*n*" attributes (sub-criteria) and score of "*m*" with respective to each "*n*" are identified:

- Let x_{ij} be the score of alternative i $(i = 1,......., m)$ with respect to sub-criterion j ($j = 1,......., n$)

- The matrix $X = (x_{ij})$ $m \times n$ *matrix* was constructed. Here, the matrix elements x_{ij} are the data values of the different sub-criteria.

Stage 1- Normalization of x_{ij} Eq. 0.4.

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_i \left(x_{ij}^{\ 2}\right)} \tag{3.4}$$

Stage 2- Weighted Normalized of x_{ij} Eq. 0.5.

$$v_{ij} = v_j \times r_{ij} \tag{3.5}$$

Stage 3- Negative Ideal Solution Eq. 0.6.

$$A^- = \{w_1^-, \ldots\ldots\ldots, w_n^-\} \tag{3.6}$$

$$w_j^- = \{\min(v_{ij}) \quad if \quad j \in J^+, \max(v_{ij}) \quad if \quad j \in J^-\}$$

Stage 4- Ideal Solution Eq. 0.7.

$$A^+ = \{w_1^+, \ldots\ldots\ldots, w_n^+\} \tag{3.7}$$

$$w_j^+ = \{\max(v_{ij}) \quad if \quad j \in J^+, \min(v_{ij}) \quad if \quad j \in J^-\}^+$$

Stage 5- Separation from Negative Ideal Solution Eq. 0.8**.**

$$S^- = \left[\sum_j \left(w_j^- - v_{ij}\right)^2\right]^{1/2} \tag{3.8}$$

Stage 6- Separation from Ideal Solution Eq. 0.9.

$$S^+ = \left[\sum_j \left(w_j^+ - v_{ij}\right)^2\right]^{1/2} \tag{3.9}$$

Stage 7- Relativeness Closeness to Ideal Solution (0 < C* < 1) Eq. 0.10.

$$C^* = S^- / \left(S^+ + S^-\right) \tag{3.10}$$

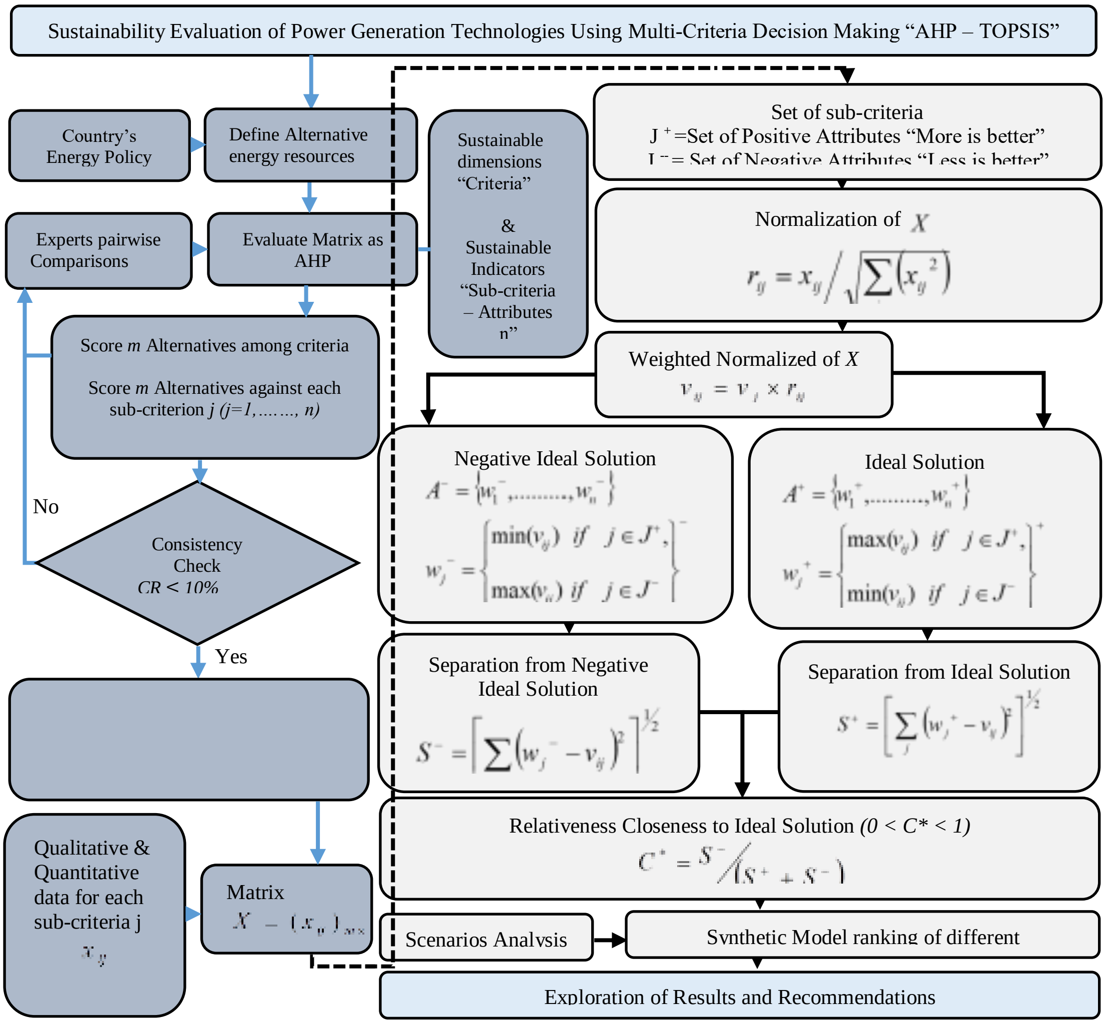


Figure 3.3: Detailed Flowchart of Sustainability Evaluation of Power Generation Technologies Using MCDM "AHP – TOPSIS"

3.3.4.3 Scenarios Analysis

In order to analyze how results behave with the change of input data, different scenarios were performed. The results (ranking) are said robust in case they do not vary with the change of input parameters (Ishizaka & Labib, 2009).Therefore, different scenarios were evaluated for this effect.

3.4 Modelling of Current and Future Energy Balance

The data used to perform the energy demand forecasting were hierarchically gathered in four levels which were: sectorial level comprising households, agriculture, industry, transport and commercial, service and other; sub-sectorial level such as urban and rural households for the residential sector; a level detailing each end-use energy option such cooking, lighting and other uses; and the fourth level categorizing each end-use option in view of fuel by device such as firewood, charcoal, electricity, kerosene, etc. Figure 3.4 presents a detailed flowchart structure used to perform the total energy demand in the different sectors.

The countries LEAP model was developed with 2015 as the base year, to analyze the possible developmental structure of energy generation system of the country up to 2040. The choice of this base year 2015 was due to a high possible availability of data and also provided opportunity to validate the results with real data for the past years (from 2015 to 2020).

Energy units and currency are expressed in TJ and USD respectively. The year 2016 was set as first year for simulation.

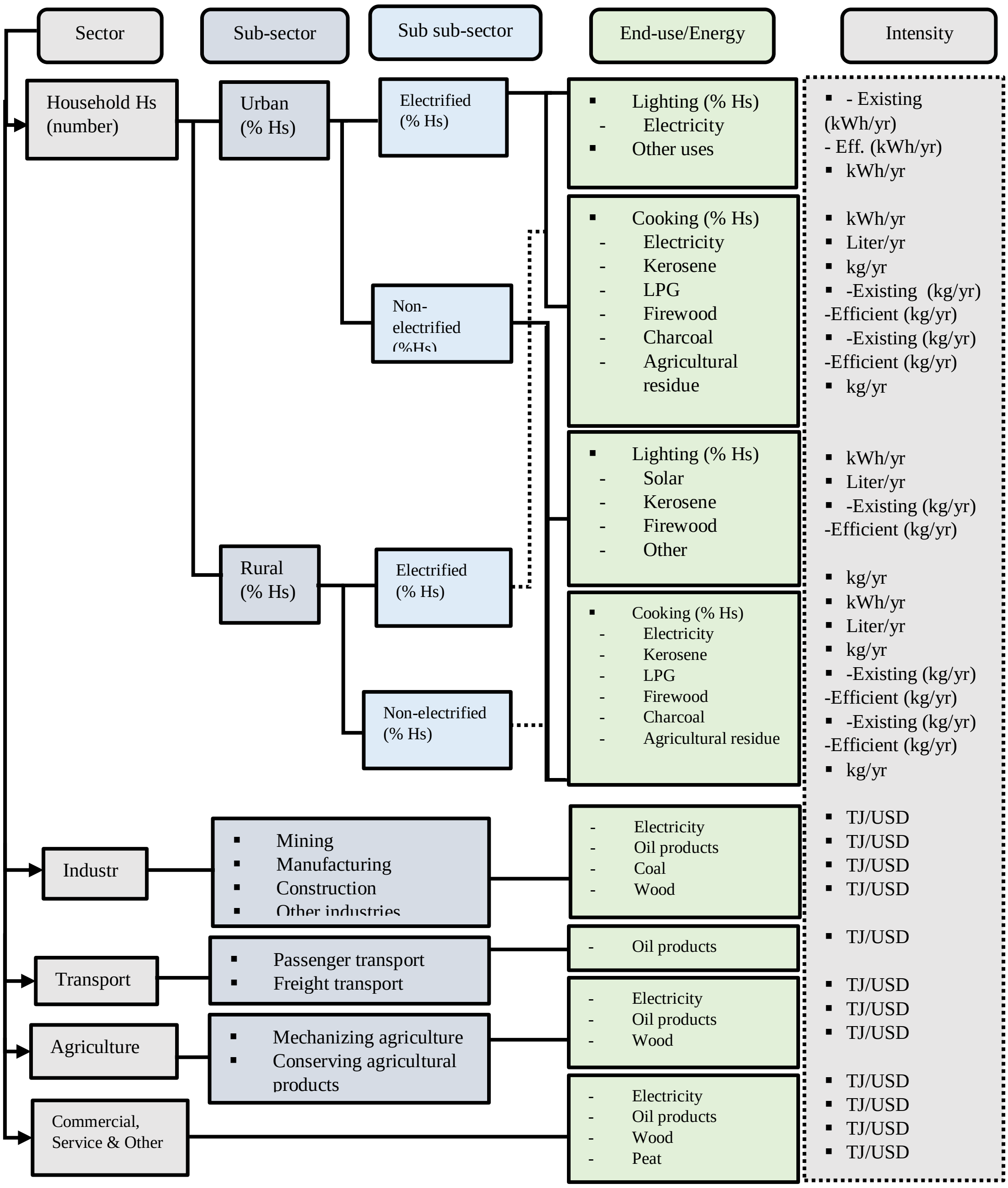


Figure 3.4: Flowchart of Total Energy Demand by Sector

Historical trends were developed based on the data of the years 2000 – 2015. Based on historical data, the average annual growth rate (AGR) method was used to determine the variations in GDP, population and energy intensity.

For energy the countries energy transformation, different modules were ordered in form of tree and sequenced in the way they reflect the energy flows in their positions. This means that transmission & distribution were positioned near the demand analysis (top of the list) while other conversion modules (e.g., electricity generation) were positioned in middle; the modules of energy resources were placed in the last position. Technical and other parameters were inputted into the model for different processes.

Figure 3.5 presents the LEAP model construction and analysis for the country's energy balance.

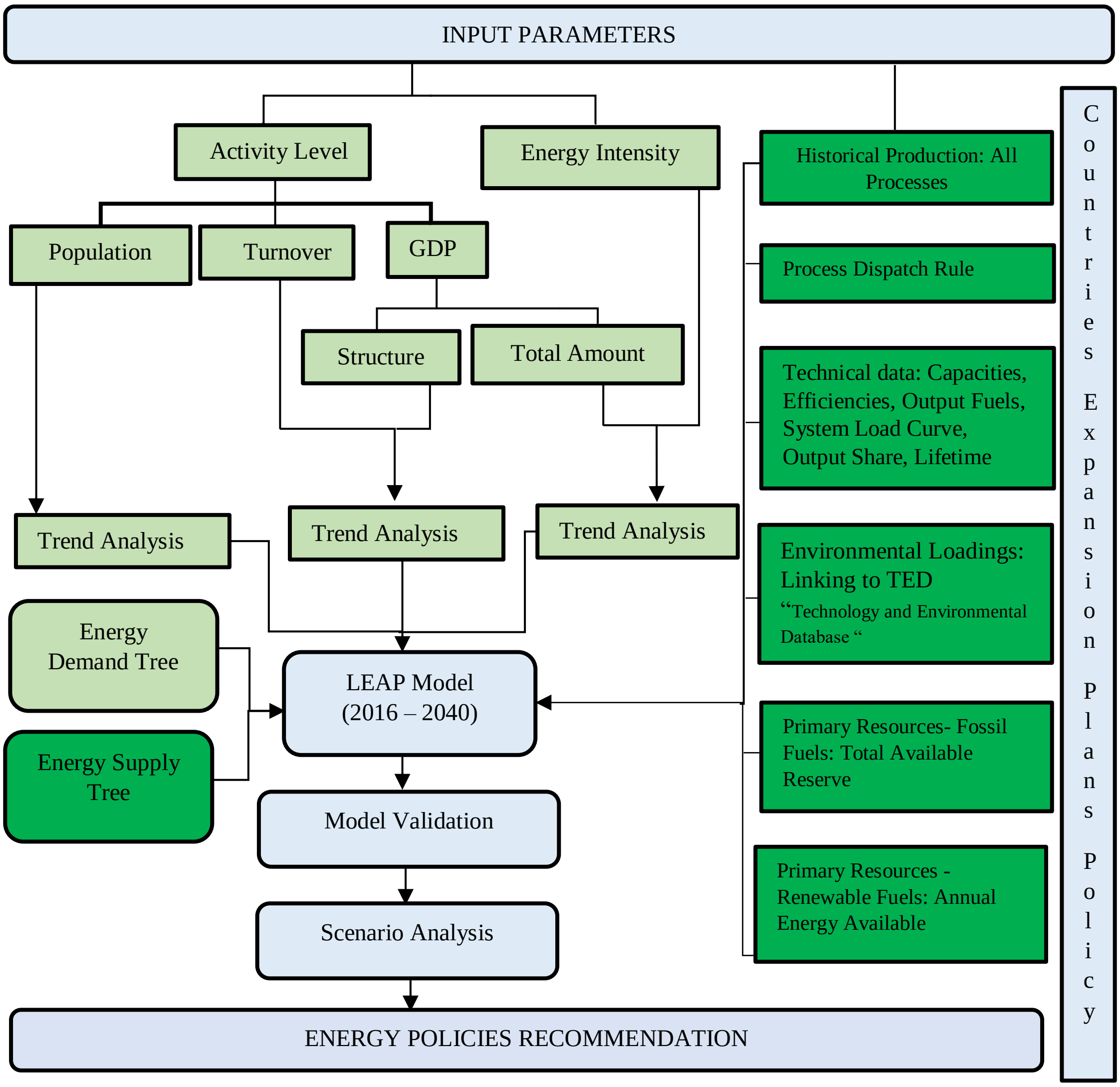


*Figure **3.5**: LEAP Model Construction and Analysis for the Countries Energy Balance*

The final energy demand (energy consumption) is calculated by Eq. 0.1:

$$ED_K = \sum_i \sum_j A_{k,j,i} \times EI_{k,j,i} \tag{3.11}$$

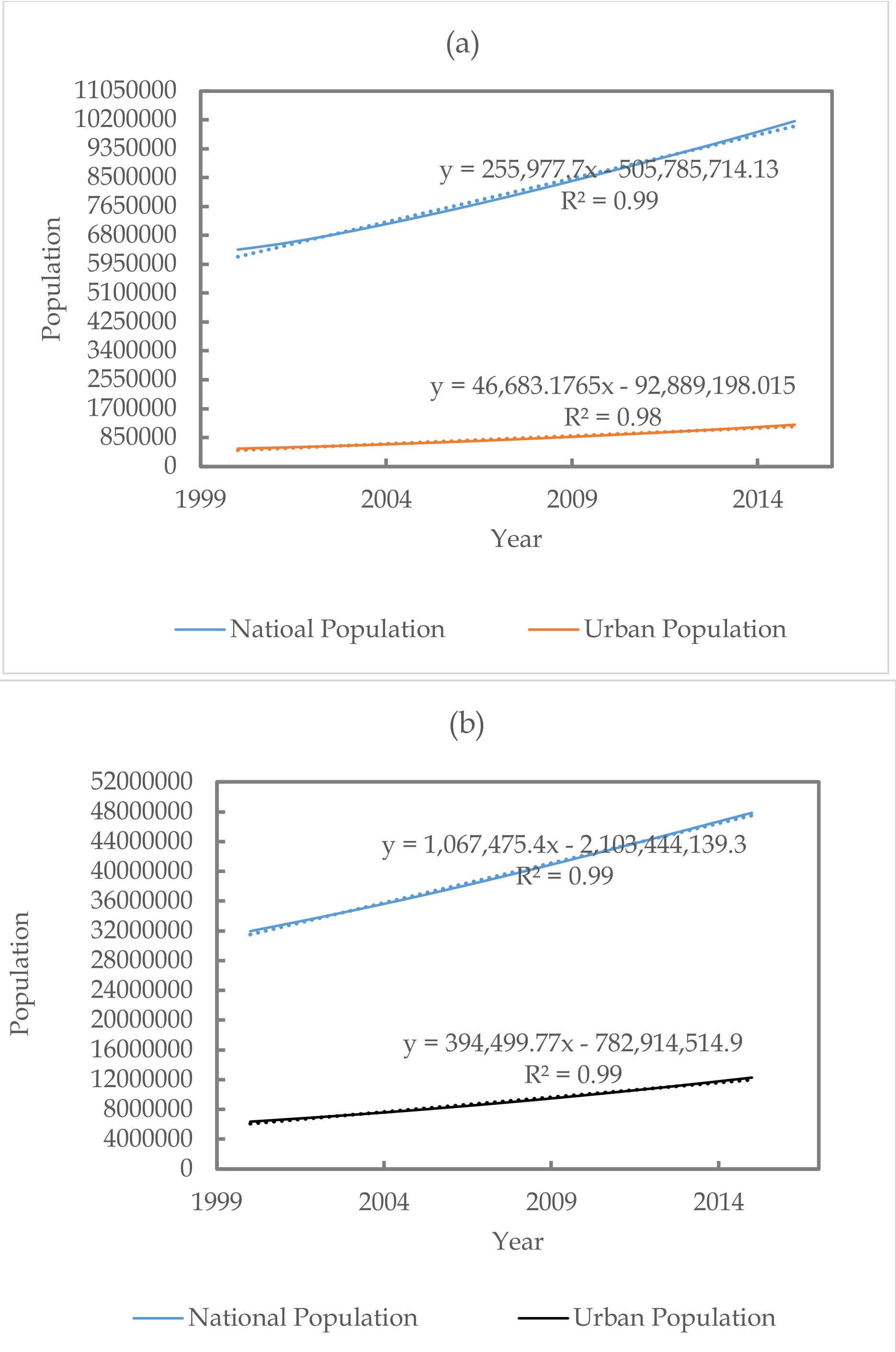
Where, ED is the total energy demand; A is the activity level (a measure of economic activity or social activity for which energy is consumed); EI is the energy intensity (energy usage per device or per GDP "translating a measuring scale of inefficiency of energy of an economy"); i and j respectively refer to the types of the sector and device/vehicle; k is the fuel type.

3.4.1 Evaluation of Key Drivers of Energy Demand

The population growth has huge impact on residential energy demand whereas economic parameters variation such as GDP growth is impacted by industrial, commercial, agricultural and service sectors activities. The economic sectors require energy as a production input with a target of minimizing their total product cost (Bhattacharyya & Timilsina, 2009). Therefore, historical and future trends on demography and GDP for these countries were evaluated. Other factors driving the energy demand such end-use fuels and technological change are also analysed.

3.4.1.1 Historical and Future Demographic Data Analysis

The historical population data of the countries were obtained from the development Indicators of the World Bank (The World Bank, 2022). Figure 3.6 shows historical trends of the population for the last fifteen years (2000 – 2015).



Source: Author's Compilation from (The World Bank, 2022)

Figure 3.6: Historical Trends of Population for (a) Burundi and (b) Kenya

According to the "United Nations, Department of Economic and Social Affairs, Population Division – UNDESA" data, Kenyan rural population is expected to be 41691000 in 2025, 44577000 in 2030, 47060000 in 2035 and 49045000 in 2040 whereas the urban population is forecasted to become 18372000 in 2025, 22383000 in 2030, 27026000 in 2035 and 32242000 in 2040 (UNDESA, 2018). The Burundian rural population is forecasted to become 11663000 in 2025, 13019000 in 2030, 14402000 in 2035 and 15828000 in 2040 while urban population is projected to grow up to 2147000 in 2025, 2780000 in 2030, 3569000 in 2035 and 4549000 in 2040 (UNDESA, 2018).

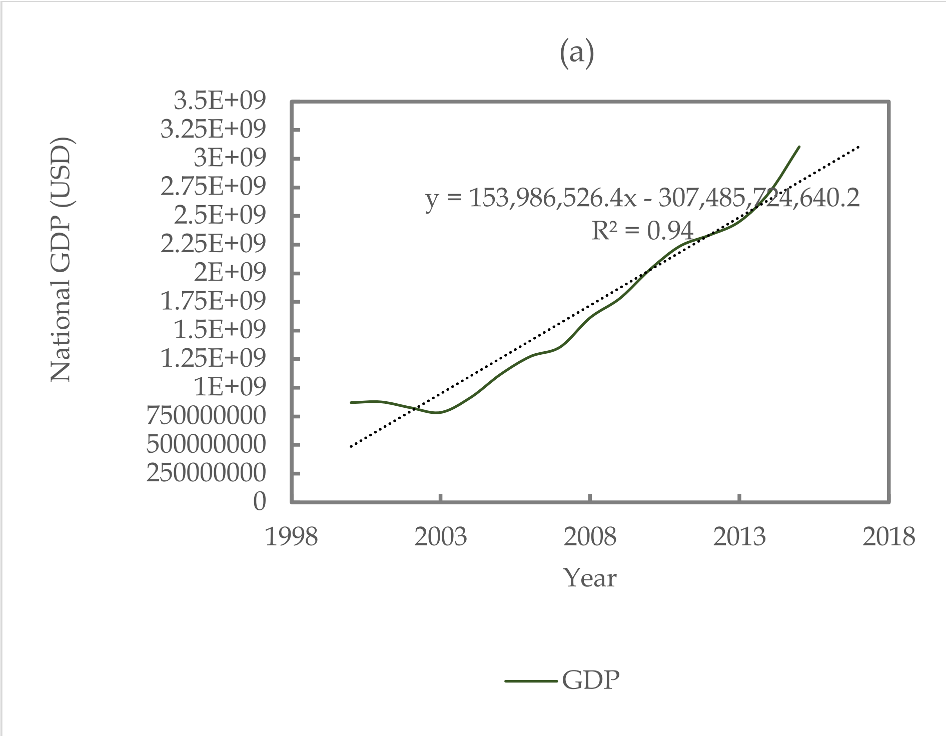
The Burundian annual percentage of population in urban area which was 12.1 % in 2015 is expected to be 15.5 % in 2025, 17.6 % in 2030, 19.9 % in 2035 and 22.3 % in 2040 (UNDESA, 2018). For the Kenyan case, it was 25.7 % in 2015 and is expected to be 30.6 % in 2025, 33.4 % in 2030, 36.5 % in 2035 and 39.7 % in 2040 (UNDESA, 2018).

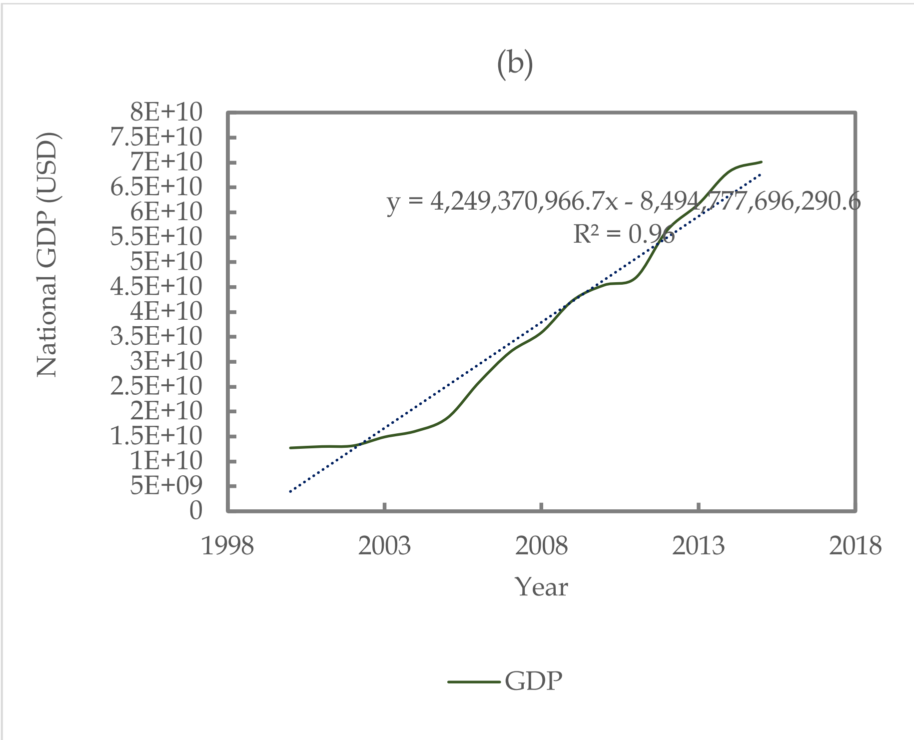
The average household size (number of members) was 4.26 in 2008, 4.78 in 2010, 4.73 in 2012 and 4.83 in 2016 for Burundi whereas it was 5.34 in 1969, 4.90 in 1989, 4.80 in 1993, 4.29 in 1998, 4.43 in 1999, 4.36 in 2003, 4.29 in 2009, 3.92 in 2014 and 3.64 in 2015 for Kenya (UNDESA, 2019).

3.4.1.2 Historical and Future Economic Data Analysis

The historical GDP data of the countries were obtained from the development indicators of the World Bank (The World Bank, 2022). Figure 3.7 shows the GDP trends of the two countries for the period of 2000 – 2015. In 2015, the national GDP growth was -3.9 % for Burundi and 4.97 % for Kenya (The World Bank, 2022).

It was expected the Kenyan economy to have a growth of 6.5 % in 2022, 6.2 % from 2018 to 2030 and 6.6 % between 2030 and 2040 (Cilliers et al., 2018). For Burundi, the data shows that the national GDP which was USD 870,486,065.88 in 2000, became USD 3,104,394,858.12 in 2015. This corresponds to 16 % of annual average GDP growth rate.

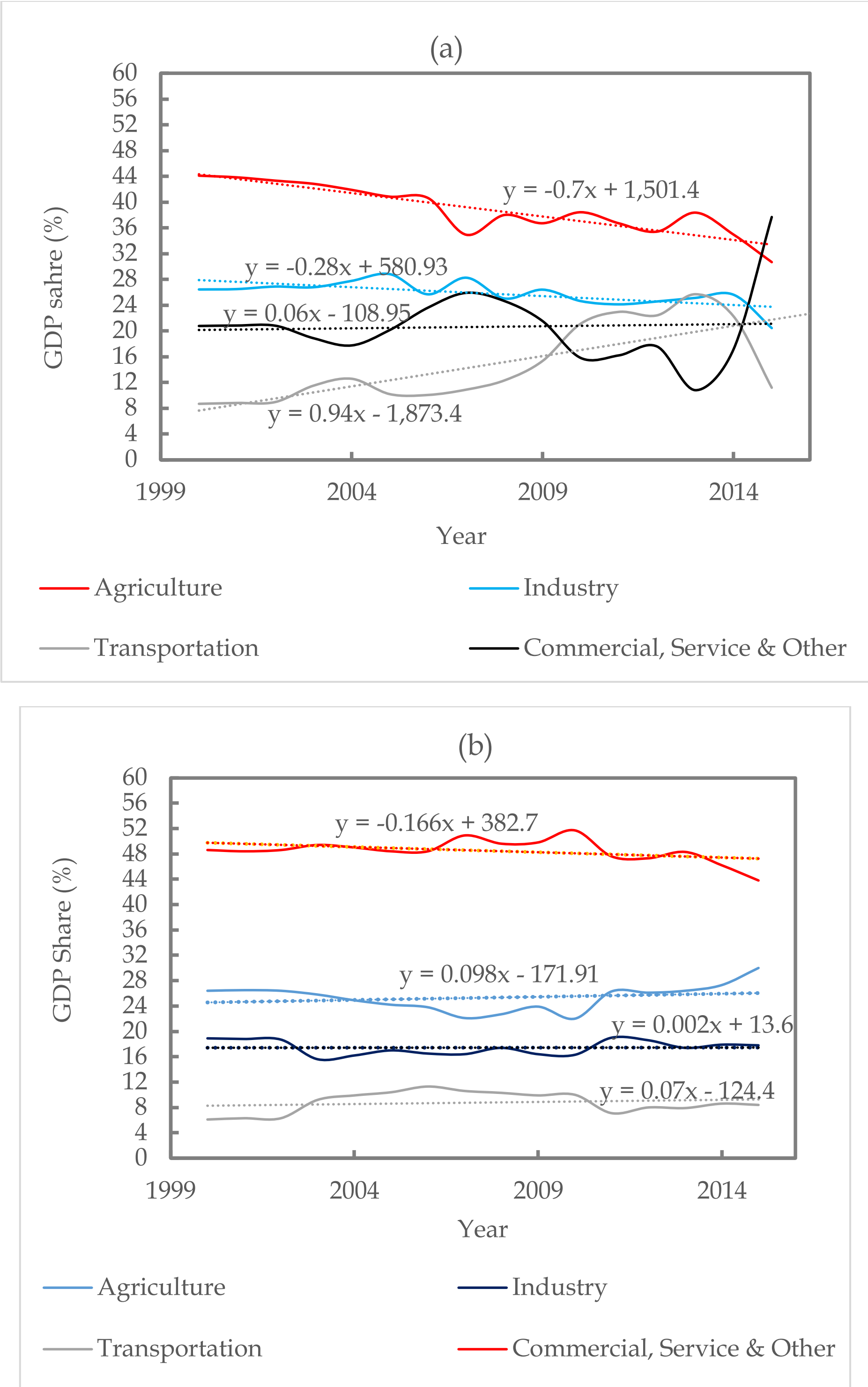




Source: Author's Compilation from (The World Bank, 2022)

Figure 3.7: Historical GDP Trends for (a) Burundi and (a) Kenya

The agriculture sector includes forestry and fishing. The industry sector includes mining, manufacturing, construction, electricity and water supply. Wholesale and retail trade; repairs, Accommodation and food service activities, Information and communication, Financial and insurance activities, Real estate, Professional, scientific and technical activities, Administrative and support service activities, public administration and defense, Education, Human health and social work activities, Arts, entertainment and recreation, Taxes on products and Other service activities are grouped under Commercial, Service and Others. These data were obtained from Kenya National Bureau of Statistics – KNBS (KNBS, 2004, 2008, 2012, 2016, 2021) for Kenya and from (The World Bank, 2022) for Burundi. The historical trends of the GDP share for Burundi and Kenya are presented in Figure 3.8.



Source: Author's Compilation from (KNBS, 2004, 2008, 2012, 2016, 2021) and (The World Bank, 2022)

*Figure **3.8**: Historical Trends of GDP Share (%) for (a) Burundi and (b) Kenya*

In 2015, the two sectors Commercial, service and other and Agriculture accounted for the largest GDP share in Kenya with 43.8 % and 30 %, respectively. The other sectors Industry and Transportation accounted for 17.8 % and 8.4 % respectively. From 2000 up to 2015, historical trend GDP share contributed by Agriculture, Industry and Transportation is increasing while the GDP share of Commercial, Service and Other has reduced. Hence, in reference scenario, these trends are expected in future. The GDP contribution of Agriculture, Industry and Transportation are expected to increase to 28.5 %, 17.5 % and 11 % by 2040, respectively whereas the GDP share of Commercial, service and other is expected to decline to 43 % by 2040.

For the case of Burundi, the same figures are noticed in 2015. The Commercial, service and other accounts for the largest GDP share of 36 % while the share of Agriculture is 31 %. Industry sector follows with 21 % while Transport has the least share of 12 %. Since 2000 up to 2015, the historical trends show GDP share contributed by Agriculture and Industry has dropped while the GDP share of Commercial, Service and Other and Transportation has increased. In reference scenario, similar trends were considered in future. The GDP contribution of Agriculture and Industry are expected to decline to 15% and 17 % by 2040, respectively whereas the GDP share of Transportation and Commercial, service and other are expected to increase to 45 % and 23 % by 2040, respectively.

3.4.2 Energy Demand Analysis

The energy demand was analyzed by considering five major sectors of economy which are: Transportation; Commercial, service and others; Industry; Residential and Agriculture. Top-down model was applied for households while bottom-up model was used for other economic sectors. This was due to data availability. In this analysis, data were obtained from different sources. Where there was lack of data availability, best guess method was used to arrive at an optimal solution. This analysis was performed considering the business-as-usual scenario (BAUS), meaning that historical trends were considered and no new policy measure was to be implemented.

Therefore, this analysis constituted the reference scenario for appraising other policies that may be implemented in the countries.

3.4.2.1 Historical and Future Energy Demand: Residential Sector Analysis

- ***Cooking***:

Biomass is the main source of energy for cooking in Burundi (Blondel, 2014; Niyongabo et al., 2022) and Kenya (Ministry of Energy, 2019).

According to the Kenya Renewable Energy Association – KEREA, a Kenyan household consumes 5 – 10 kg of firewood per day (KEREA, 2022) making 1825 – 3650 kg/yr. Therefore, the consumption of 3650 kg/yr was used in this research as it was found to be close to similar values found in other references: on average, a Kenyan urban household consumes a bundle of 20 kg of firewood within 2 days (UNIDO, 2015) translating 3650 kg/yr; on average, an annual firewood consumption in Kenyan urban and rural areas is respectively 2,701 kg/household and 3,394 kg (Ngigi, 2008). On average, 0.67 kg/person is a daily charcoal consumption in Kenya when using traditional stoves (Karekezi et al., 2004). A similar value was suggested by (Barnes et al., 1993) where he indicated an average per capita consumption of 0.7 kg/per in Kenya for households with traditional stoves. Therefore, considering the average Kenyan household size of 3.64 in 2015 (UNDESA, 2019), this translates a household charcoal consumption 890 kg/yr for households using traditional stoves.

In 2015, the Burundian population was 10.16 million while urban population was 1.23 million (The World Bank, 2022). With an average household size of 4.83 (UNDESA, 2019), this reflects 2.1 million of total households and 0.26 million of urban households in 2015. The Burundian residential sector consumes 98 % of total wood produced in the country (Ministry of Energy and Mining, 2011). In 2015, a total of 10162300 tonnes of firewood were consumed in Burundi (ISTEEBU, 2019) and 77.2 % of Burundian households were using firewood for cooking (ISTEEBU, 2017), this reflects an annual consumption of 6143 kg/yr and was used in this research as it is close to the suggested value of 7.1 ton/household by (Lighting Global, 2020). Considering that 12.9 % households were using charcoal for cooking (ISTEEBU, 2017), this reflects an annual consumption of 1782.2 kg/household. Hence, charcoal consumption of 1782.2 kg/household was adopted to be used in this study as it was found very similar to the estimated 1700 kg/household by (Lighting Global, 2020) for Burundi. Furthermore, a similar value was found in the research of Gaspard et al. where a Burundian urban household was found to have an average consumption of 4.67 kg/day of charcoal, translating 1704.55 kg/yr (Gaspard et al., 2015). In 2015, 482802 tons of charcoal were consumed in Burundi (Niyongabo et al., 2022). The cost of firewood is estimated at 53.5 Fbu/kg in Burundi (Niyongabo et al., 2022) and 30 KSh/kg in Kenya according to Energy and Petroleum Regulatory Authority - EPRA (EPRA, 2022) while the charcoal price is 500 Fbu/kg in Burundi (Niyongabo et al., 2022). The heating values for these fuels are 15 GJ/ton (conversion efficiency: 0.17) and 31 GJ/ton (conversion efficiency: 0.31) for firewood and charcoal respectively (Ministry of Energy, 2019).

Regarding other fuel types, it was estimated that a Kenyan household uses 114 kg/yr (163 kg/yr in urban and 78 kg/yr in rural) of kerosene and 57 kg/yr (68 kg/yr for urban and 47 kg/yr for rural households) of LPG (Ministry of Energy, 2019). In Burundi, Kerosene is marginally used for cooking purposes; it is instead most used for lighting (Niyongabo et al., 2022). Other fuels such as crop residues are also used on an annual average of 400 kg/yr (270 kg/yr in urban and 421 kg/yr in rural) in Kenya (Ministry of Energy, 2019) this was also assumed for Burundi. In Burundi, peat is also marginally used for cooking purposes (ISTEEBU & INSP, 2013; ISTEEBU, 2017). Hence, considering the calorific value of 14.7 MJ/kg for peat (Manirakiza et al., 2020) and the amount of energy required by a Burundian household for cooking when using charcoal, it was found that about 3545.4 kg/yr of peat per household is used. The average cost of kerosene was 2200 Fbu/l in Burundi (Niyongabo et al., 2022) and 58.4 KSh/l in Kenya (KNBS, 2016) while the LPG price was and 192.78 KSh/kg in Kenya (KNBS, 2016) in 2015. The heating values for these fuels are 43.8 GJ/ton (conversion efficiency: 0.5) and 47.3 GJ/ton (conversion efficiency: 0.54) for kerosene and LPG respectively (Ministry of Energy, 2019).

In 2015, the Kenyan electrification rate was 41.6 % and out of the electrified households, 78.1 % were urban while 29 % were rural while it was 8.4 % (57.1 % in urban area and 1.7 % in rural area) for Burundi (The World Bank, 2022). These values were 49.8 % in urban and 6.5 % in rural for Kenya in 2000 whereas they were 52.4 % in Burundian urban area and only 1 % in Burundian rural area in 2013 (The World Bank, 2022). This implies an average yearly increase by 1.9 % in urban and 1.5 % in rural for Kenya and a yearly increase by 2.35 % in urban and 0.35 % in rural for Burundi. Due to the rapid increase of power projects for rural electrification in Kenya, it was assumed, in reference scenario, similar trends to be expected with a yearly increase of 2 % in urban and 3 % in rural. From the households with grid access, 3 % and 1 % households use electric cooking stoves as secondary and primary technology respectively (Ministry of Energy, 2019). From the electrified households, only 0.4 % and 0 % households use electricity for cooking in urban and rural areas respectively (Ministry of Energy, 2019). For the case of Burundi, 8.4 % of households were electrified in 2015 and out them, 1.7 % were rural while 57.1 % were urban. As most electric stoves range between 1 and 3 kW of power capacity, it was assumed that, on average, 1080 kWh/yr per household is needed for cooking considering a stove of 1 kW with 3 h/day. The cost of electricity is estimated at 20 USD /kWh (exchange rate of December 31, 2019: FBu 1,879 = US$1) in Burundi (The World Bank, 2020) and 25 KSh/kWh in Kenya (EPRA, 2022) for residential sector. We should note that in both countries, a certain number of households use more than one technology for cooking. For instance, it was found that more than 51 % households use more than one technology in Kenya (Ministry of Energy, 2019). Hence, preferred primary cooking technology was only considered in this study for simplicity.

The amount of charcoal demand in Kenya which was estimated at 16.3 million cubic meters was expected to increase by 17.8 % by 2032 (Ministry of Energy, 2020). The charcoal stoves are relied on by 42.3 % households (47.0 % in urban and 40.1 % in rural) (Ministry of Energy, 2019).

In 2015, Kenya accounted for 15.3 % households using charcoal stoves with 22.8 % in urban and 9.4 % in rural (Ministry of Energy, 2019). These proportions were 13.6 % (30.9 % in urban and 7.9 % in rural) in 2005 (Ministry of Energy, 2019). In 10 years, there has been a national increase of 1.7 %. In rural area, there is an increase of 1.5 % while there is a drop of 8.1 % in urban area. The reference scenario assumed that similar trends are expected in future. A marginal increase by 1 % and 1.5 % in electrified and non-electrified rural area respectively and a drop by 2 % and 1 % in electrified and non-electrified urban area respectively, every five years as from 2016.

In 2015, Kenya accounted for 54.6 % households using woodstoves with 16.7 % in urban and 84.5 % in rural (Ministry of Energy, 2019). These proportions were 69.2 %

(10.1 % in urban and 88.9 % in rural) in 2005 (Ministry of Energy, 2019). In 10 years, there has been a national decrease of 14.6 %. While there is a decrease of 4.4 % in rural area, there has been recorded an increase of 6.6 % in urban area. This may be justified by a high urbanization rate where many people have moved from rural to urban area. Despite the Kenyan ambitions for clean cooking fuels, the firewood will still play an important role in cooking sector. Therefore, the reference scenario assumed that the same trends will continue and that it will marginally drop by 2.5 % in rural (2 % for electrified and 0.5 % for non-electrified households) with an increase of 3.5 % in urban area (1% for electrified and 2.5 % for non-electrified households) in every five years as from 2016.

Kenyan households using Kerosene stoves were estimated at 12.8 % (47.7 % in urban and 2.3 % in rural) in the year 2005 while the proportions were 13.9 % (29.0 % in urban and 2.2 % in rural) in 2015 (Ministry of Energy, 2019). Within the period of 10 years, there is marginal drop of 1.1 % at country level. We can notice a significant increase of 18.7 % in urban and a slight increase of 0.1 % in rural. For the case of households using LPG, there was recorded 3.4 % (11.7 % in urban and 0.6 % in rural) in 2005 whereas the records show 13.3 % (27.5 % in urban and 2.4 % in rural) in 2015 (Ministry of Energy, 2019). We can notice a significant increase of 9.9 % (15 % in urban and 0.5 % in rural). The share of households using electric cooker was very low in 2005: 0.4 % (1.3 % in urban and 0.2 % in rural). In 2015, this share dropped to 0.3 % (0.6 % in urban and 0.1 % in rural) (Ministry of Energy, 2019). Nevertheless, the Kenyan Government intended to discourage domestic use of Kerosene fuel while encouraging the use of other alternatives such as LPG. Hence, this trend was expected to suddenly drop for Kerosene and sharply increase for LPG as result of new levies and taxes imposed by the Government as from 2015 (Ministry of Energy, 2020). Therefore, the reference scenario assumed a yearly drop by 1 % in urban and 0.1 % in rural for Kerosene use and yearly increase by 1 % in urban and 0.1 % in rural for LPG use as from 2016. Due to significant increase of number of electrified households in Kenya ref, the reference scenario assumed a slight increase of electricity usage for cooking by 0.6 % in urban and 0.1 % in rural in every 5 years. The use of other means was assumed to follow the similar trends.

In 2010, according to a study conducted by Burundi Office of National Statistics and Economic Studies (ISTEEBU) and National Institute of Public Health (INSP), 8.3 % of Burundian households (70 % of urban households and 2.2 % of rural households) used charcoal for cooking (ISTEEBU & INSP, 2012). The firewood was used by 84.7 % of Burundian households (20 % urban households and 91.2 % of rural households) (ISTEEBU & INSP, 2012). Households using Straw/shrubs/grass for cooking were 5.5 % (1.1 % urban households and 5.9 % of rural households) and 0.2 % (1.3 % urban households and 0.1 % of rural households) households used of other means (ISTEEBU & INSP, 2012).

In 2012, Households using electricity for cooking were 0.0 % (0.0 % of urban households against 0.0 % of rural households) and 0.1 % urban households and 0.0 % of rural households used peat (ISTEEBU & INSP, 2013). Households using charcoal for cooking were 9.8 % (74.2 % of urban households against 3.2 % of rural households) and 75.0 % (15.1 % urban households and 81.1 % of rural households) households used firewood (ISTEEBU & INSP, 2013). 12.1 % households (1.1 % urban households and 13.2 % of rural households) used Straw/shrubs/grass. 1.3 % households (0.5 % urban households and 1.3 % of rural households) used agricultural residues (ISTEEBU & INSP, 2013).

In 2016, Households using electricity for cooking were 0.1 % (0.4 % of urban households against 0.1 % of rural households) and 0.1 % households (0.4 % urban households and 0.1 % of rural households) used peat (ISTEEBU, 2017). Households using charcoal for cooking were 12.9 % (75.4 % of urban households against 5.2 % of rural households) and 77.2 % (16.3 % urban households and 84.7 % of rural households) households used firewood. 8.3 % households (1.2 % urban households and 9.1 % of rural households) used Straw/shrubs/grass. 0.2 % households (0.2 % urban households and 0.2 % of rural households) used agricultural residues (ISTEEBU, 2017).

According to the study conducted by ISTEEBU) and INSP, 8.3 % of Burundian households (70 % of urban households and 2.2 % of rural households) used charcoal for cooking in 2010. In 2016, households using charcoal for cooking were 12.9 % (75.4 % of urban households against 5.2 % of rural households). In the lifespan of 6 years, we can notice an increase of charcoal use by 4.6 % at national level (increase by 5.4 % in urban area and by 3 % in rural area). The use of firewood has registered a trivial decrease between the year 2010 and 2016.

In 2010, 84.7 % households (20 % urban households and 91.2 % of rural households) used firewood (ISTEEBU & INSP, 2012) against 77.2 % (16.3% urban households and 84.7 % of rural households) in 2016 (ISTEEBU, 2017), reflecting a decrease by 3.7 % in urban area and 6.5 % in rural area. The use of electricity for cooking purposes is negligible in Burundi, almost all households have been using other means for cooking apart from electricity (ISTEEBU & INSP, 2012, 2013). In 2016, 0.1 % households (0.4 % of urban households against 0.1 % of rural households) used electricity for cooking purposes (ISTEEBU, 2017). The use of peat for cooking has also registered a slight increase between the years 2012 and 2016. In 2012, 0.1 % urban households and 0.0 %

of rural households used peat for cooking (ISTEEBU & INSP, 2013) while these shares became 0.1 % households at national level (0.4 % urban households and 0.1 % of rural households) in 2016 (ISTEEBU, 2017).

The reference scenario assumed that similar trends were to be expected in future. For charcoal use, a yearly increase by 0.9 % in urban area and by 0.5 % in rural area was considered whereas a marginal yearly drop by 0.62 % in urban area and by 1.1 % in rural area was considered for firewood. Despite the efforts to increase electric power, the installed power capacity in the country is still very low with frequent load shedding. Therefore, we assumed that the share of population using electricity will remain very low and a marginal yearly increase by 0.2 % in urban area and 0.05 % in rural area was considered. By considering the historical trend of use of peat for cooking, an annual increase by 0.075 % in urban area and by 0.025 % in rural area was considered in the reference scenario.

The energy saving by using improved stoves (charcoal and wood) can reach 50 % as compared to traditional stoves (Aera, 2021; Barnes et al., 1993; Njogu & Kung, 2015) in terms of fuel consumption.

In 2015, only 8.2 % of Kenyan households (3.0 % in urban and 12.8 % in rural) were using improved wood stoves (Ministry of Energy, 2019). The high adoption of efficient wood cook stoves is found in rural area as shown by the historical trend: 1.0 % in urban against 10.9 % in rural in 2005/2006; 3.0 % in urban against 12.8 % in rural in 2015/2016; 3.7 % in urban and 14.9 % in rural in 2018 (Ministry of Energy, 2019). The reference scenario assumed that the historical trend will be expected in future with annual growth of 0.2 % for urban and 0.19 % for rural households.

In 2015, only 6.2 % of Kenyan households (9.3 % in urban and 3.7 % in rural) were using improved charcoal stoves (Ministry of Energy, 2019). The high adoption of efficient charcoal stoves is found in urban area as shown by the historical trend: 14.3 % in urban against 3.9 % in rural in 2005/2006; 9.3 % in urban against 3.7 % in rural in 2015/2016; 14.8 % in urban and 6.6 % in rural in 2018 (Ministry of Energy, 2019). The reference scenario assumed that the historical trend will be expected in future with annual growth of 1.8 % for urban and 0.9 % for rural households.

The penetration is very low in Burundi and only a marginal adoption improved charcoal stoves were noticed. From the year 2010, about 3,000 improved stoves were distributed in Burundi under the project sustainable energy production funded by the Kingdom of the Netherlands (Ministry of Energy and Mining, 2011). Considering the 2.1 million households in base year and that 12.9 % households (75.4 % urban households and 5.2 % of rural households) were using charcoal stoves for coking in the base year (ISTEEBU, 2017), the 3,000 improved stoves (2,000 in urban and 1,000 in rural) corresponds to only 1.1 % households (0.01 % in rural and 0.01 % in urban) with improved charcoal stoves. By 2025, the Power company Area expects that 500,000 households in Burundi will equipped with improves cook-stoves (Aera, 2021), representing about 25 % of total households. This company aimed at distributing 6,000 improved stoves per month as from 2018 (Aera, 2021). Therefore, the reference scenario assumed a marginal annual growth of 0.3 % and 1.2 % for rural and urban households respectively as from 2018.

These cooking energy intensities are summarized in Table 3.8 and Table 3.9 for Kenya and Table 3.10 for Burundi.

- ***Lighting*:**

In the both countries, different fuels, other than electricity are used for lighting, especially in rural areas. For lighting fuels, a Kenyan household spends about 170.76 KSh/month and 579.67 KSh/month on kerosene and electricity respectively (Baek et al., 2020) while the expenditure averages 100 KSh/month for households using fuel wood for lighting (Lighting Africa, 2012). Other lighting fuels also contribute in the overall lighting needs for households. It was found that 120 KSh/month is spent as additional lighting fuels in Kenya especially by households without grid access (Lighting Africa, 2012). These additional alternative fuels are mostly kerosene and other fuels such as dry cells (Lighting Africa, 2012). According to Dominguez et al., most households relying on solar home systems (SHS) own 5.27 W for light bulbs and 6.17 W for security lights and are likely to consume 108 kWh/yr (Dominguez et al., 2021). Considering the different fuels unit costs in 2015, it is deduced that a household consumes 278.24 kWh/yr of electricity, 35.09 l/yr of kerosene, 40 kg/yr of fuel wood and 24.66 l/yr of other fuels (supposed to be kerosene) for lighting. In rural area, it was found out that most households with grid access own 31.64 W for light bulbs and 28 W for security lights (Dominguez et al., 2021). Assuming 5 h for light bulbs and 12 h security lights per day, this implies 178 kWh/yr. The lighting energy intensities of electricity, kerosene, fuel wood and other fuels were considered to be the same for the two countries as their households' characteristics are much similar.

The kerosene used for lighting (fueling tin lamp, lantern and pressure lamp) represents 69 % (84.1 % in rural and 46.3 % in urban) in Kenya (KNBS & SID, 2013) while it is 14.2 % (9.2 % of urban households and 14.9 % of rural households) in Burundi (Belhaj et al., 2016).

Other fuels for lighting, e.g. gas lamp, torches, candles also exist in these countries and are estimated at 2 % (1.7 % in rural and 1.2 % in urban) in Kenya (KNBS & SID, 2013). Only 7.2 % of Burundian households used electricity for lighting (40.8 % of urban households and 2 % of rural households)-(Belhaj et al., 2016). Solar energy used for lighting represents 2 % (2.2 % in rural and 0.7 % in urban) in Kenya (KNBS & SID, 2013) and 0.8 % (0.7 % of urban households and 0.8 % of rural households) in Burundi (Belhaj et al., 2016). Fuel wood is also used for lighting, mostly in rural area and this represents 4 % (6.7 % in rural and 0.4 % in urban) for Kenya (KNBS & SID, 2013) and 24.6 % (10.9 % of urban households and 27 % of rural households) for Burundi (Belhaj et al., 2016).

In both countries, all electrified households are expected to only use electricity for lighting in reference scenario and other fuels would also be used by the non-electrified households as per their historical trends. The use of kerosene for lighting has registered a declining historical trend in Burundi. In 2013, 14.2 % households (9.2 % of urban households and 14.9 % of rural households) used kerosene for lighting (Belhaj et al., 2016) and the share became 1.6 % (1.5 % of urban households and 1.6 % of rural households) in 2019 (ISTEEBU, 2021). In 2012, only 0.7 % households (0.8 % of urban households and 0.7 % of rural households) used solar for lighting, before this share registered a national slight increase to 0.8 % at national level with an increase to 0.8 % rural area while there is a marginal decline to 0.7 % in urban area in 2013 (Belhaj et al., 2016). Hence, the Burundian urban households are likely to abandon solar for lighting as they become connected to the national grid. The use firewood for lighting has a declining trend as its national share was 15.2 % (5.9 % of urban households and 16.1% of rural households) in 2012 (Belhaj et al., 2016) before dropping to 7.1 % (1.8 % of urban households and 7.8 % of rural households) in 2019 (ISTEEBU, 2021).

Similar trends were considered in reference scenario. As the use rate is almost constant, it was assumed to remain constant in urban area before slightly dropping to 0.4 % for the households not connected to grid while there is a yearly growth by 0.1 % for rural households. A yearly decline of use of kerosene by 1.28 % for urban households and 2.2 % for rural households was considered. Similarly, the use of firewood for lighting is expected with a yearly decline by 0.6 % for urban households and 1.2 % for rural households.

The efficient lamps such as compact fluorescent lamps are able to save about 70 % (Khan & Abas, 2011) as compared to electric bulbs. In order to improve energy efficiency, more than 4 million compact fluorescent lamps (CFL) were distributed in Kenyan residential sector as from 2010 and the energy saved due to the efficient lamps was estimated at 155 MW (Ministry of Energy, 2020). In 2015, with the population of 47.8 million (The World Bank, 2022), the Kenyan average household size was 3.64 (UNDESA, 2019). This reflects 13.1 million households in 2015. Assuming that 10 lamps were installed per household, it was estimated that 7 % of electrified Kenyan households used efficient lighting in the base year. From the 4 million CFL (considering 3 million and 1 million respectively distributed to urban and rural households), this makes 11.4 % and 3.5 % of the electrified urban and rural households using efficient lighting in the base year. As a national strategy to improve energy efficiency, an annual increase of 3 % of efficient lighting in the Kenyan electrified households as from 2020 was expected (Ministry of Energy, 2020) and an annual increase of 2 % and 1 % used in the reference scenario for Kenyan urban and rural electrified households as from 2020.

As part of demand side management to save energy consumption at household level, the Burundian government launched a program of replacing existing incandescent bulbs by distributing 200,000 compact fluorescent lamps (CFL) and this was estimated to with an impact of saving nearly 5 MW by 2011 (African Development Bank, 2009; Ministry of Energy and Mining, 2015). Considering that the Burundian population was 10.16 million in 2015 (The World Bank, 2022) with an average household size of 4.83 (UNDESA, 2019), this reflects 2.1 million households in 2015. Therefore, 11 % of the electrified Burundian households used efficient lighting in the base year by considering 10 lamps per household, the average number for many Burundian households (Ministry of Energy and Mining, 2015). By considering the 200,000 CFL (150,000 CFL and 50,000 CFL distributed to electrified urban and rural households respectively), this makes 10 % and 16 % of the electrified urban and rural households with efficient lighting by 2015. The Burundian Government's program for energy efficiency target was to have distributed about 400,000 efficient lamps by 2022 (Ministry of Energy and Mining, 2015). Therefore, the reference scenario assumed an annual increase by 2 % and 1 % for urban and rural households respectively, as from 2015.

These lighting energy intensities are summarized in Table 3.8 and Table 3.9 for Kenya; and Table 3.10 for Burundi.

- ***Other Electrical Appliances:***

According to the report of UNDP and Global Village Energy Partnership-GVEP, on average, a Kenyan household consumes 694 kWh/yr (UNDP & GVEP, 2005). According to Fobi et al., urban Kenyan households consume much electricity as compared to rural customers and the difference tends to reach 50 % (Fobi et al., 2018). Urban customers are likely to consume 43 kWh/month (Fobi et al., 2018), the consumption reflecting 516 kWh/yr. In contrast, it was estimated that an average Kenyan household consumption is 300 kWh/yr (Moksnes et al., 2020) and this was assumed to be the level for rural households in this study. For the considered base year, it is obvious that, from the previous analyses, most of the households use electricity for lighting purposes with negligible usage for cooking in both countries.

Therefore, taking into account the consumption for lighting per household, this translates a consumption of 237.76 kWh/yr in urban area and 122 kWh/yr in rural by other electrical appliances such as radio, television, telephone and others.

As most found appliances in Burundian urban area are radio, television, telephone (ISTEEBU & INSP, 2012; ISTEEBU, 2017), a monthly average consumption was assumed to be 30 kWh for urban household as it is close to the most monthly purchased electricity category of 0 – 50 kWh/month in Burundi. An annual consumption of 200 kWh was assumed for a Burundian rural household where radio and telephone are the most used appliances (ISTEEBU & INSP, 2012; ISTEEBU, 2017). This reflects that about 72 kWh/yr and 22 kWh/yr per household are consumed in urban and rural areas, respectively by other electrical appliances. This low household consumption in Burundi may be explained by frequent load shedding and service interruption; the electricity supply gap was estimated to be 15 GWh (5 % of total supply) and 29 GWh in 2015 and 2017, respectively (The World Bank, 2019a). Furthermore, it was found that 16.6 outages per month were experienced in this country which was higher than an average of 8.6 in Sub-Saharan Africa (The World Bank, 2019a).

Due low energy consumption caused frequent power outages in Burundi (The World Bank, 2019a), which would be one of the limitations for the adoption of "other appliances" by customers, the reference scenario assumed that electricity consumed by other electrical appliances is expected to slightly grow, especially in urban area due to expected increase electrification rate. The assumptions are 1 % and 0.2 % in Burundian urban and rural area, respectively.

These energy intensities for other appliances are summarized in Table 3.8 and Table 3.9 for Kenya and Table 3.10 for Burundi.

Table 3.8: Energy Intensity in Urban Residential Sector for Kenya: Base year 2015

Sub-sector	End-use	Fuel	Share	Energy Intensity	Units
Electrified: 78.1 %	Cooking : 100 %	Electricity	0.4 %	1080	kWh/yr/ Hs
		LPG	55.7 %	68	kg/yr/Hs
		Kerosene	17.8 %	163	kg/yr/Hs
		Other	0.1 %	270	kg/yr/Hs
		Firewood	10.7 %	3650	kg/yr/Hs
		Charcoal	15.3 %	890	kg/yr/Hs
	Lighting: 100 %	Electricity	100 %	278.24	kWh/yr/ Hs
	Other: 100 %	Electricity	100 %	237.76	kWh/yr/ Hs
Non-electrified: 21.9 %	Cooking: 100 %	Electricity	0.4 %	1080	kWh/yr/ Hs
		LPG	6.7 %	68	kg/yr/Hs
		Kerosene	8.6 %	163	kg/yr/Hs
		Other	0.0 %	270	kg/yr/Hs
		Firewood	62.8 %	3650	kg/yr/Hs
		Charcoal	21.5 %	890	kg/yr/Hs
	Lighting: 100 %	Solar	0.7 %	108	kWh/yr/ Hs
		Kerosene	46.3 %	35.09	l/yr/Hs
		Firewood	0.4 %	40	kg/yr/Hs
		Other	52.6 %	24.66	l/yr/Hs

Note: Hs – Household

Table 3.9: Energy Intensity in Rural Residential Sector for Kenya: Base year 2015

Sub-sector	End-use	Fuel	Share	Energy Intensity	Units
Electrified: 29 %	Cooking : 100 %	Electricity	0.0 %	1080	kWh/yr/Hs
		LPG	14.9 %	47	kg/yr/Hs
		Kerosene	1.2 %	78	kg/yr/Hs
		Other	0.6 %	421	kg/yr/Hs
		Firewood	74.3 %	3650	kg/yr/Hs
		Charcoal	9.0 %	890	kg/yr/Hs
	Lighting: 100 %	Electricity	100 %	178	kWh/yr/Hs
	Other: 100 %	Electricity	100 %	122	kWh/yr/Hs
Non-electrified: 71 %	Cooking: 100 %	Electricity	0.0 %	1080	kWh/yr/Hs
		LPG	1.8 %	47	kg/yr/Hs
		Kerosene	0.4 %	78	kg/yr/Hs
		Other	0.0 %	421	kg/yr/Hs
		Firewood	91.2 %	3650	kg/yr/Hs
		Charcoal	6.6 %	890	kg/yr/Hs
	Lighting: 100 %	Solar	2.2 %	108	kWh/yr/Hs
		Kerosene	84.1 %	35.09	l/yr/Hs
		Firewood	6.7 %	40	kg/yr/Hs
		Other	1.7 %	24.66	l/yr/Hs

Note: Hs – Household

Table 3.10: Energy Intensity in Residential Sector for Burundi: Base year 2015

Sub-sector	End-use	Fuel	Share	Energy Intensity	Units
Urban	Cooking : 100 %	Electricity	0.4 %	1080	kWh/yr/Hs
		LPG	0 %	47	kg/yr/Hs
		Kerosene	0 %	78	kg/yr/Hs
		Firewood	16.3 %	6143	kg/yr/Hs
		Charcoal	75.4 %	1782.2	kg/yr/Hs
		Peat	0.4 %	3545.4	kg/yr/Hs
		Other	7.5 %	421	kg/yr/Hs
	Lighting: 100 %	Electricity	60.5 %	278.24	kWh/yr/Hs
		Kerosene	1.5 %	35.09	l/yr/Hs
		Firewood	1.8 %	40	kg/yr/Hs
		Solar	8.1 %	108	kWh/yr/Hs
		Other (, etc)	28.1 %	24.66	l/yr/Hs
	Other: 100 %	Electricity	100 %	72	kWh/yr/Hs
Rural	Cooking: 100 %	Electricity	0.1 %	1080	kWh/yr/Hs
		LPG	0 %	47	kg/yr/Hs
		Kerosene	0 %	78	kg/yr/Hs
		Firewood	84.7 %	6143	kg/yr/Hs
		Charcoal	5.2 %	1782.2	kg/yr/Hs
		Peat	0.1 %	3545.4	kg/yr/Hs
		Other	9.9 %	421	kg/yr/Hs
	Lighting: 100 %	Electricity	2.6 %	178	kWh/yr/Hs
		Kerosene	1.6 %	35.09	l/yr/Hs
		Firewood	7.8 %	40	kWh/yr/Hs
		Solar	12.4 %	108	kWh/yr/Hs
		Other (, etc)	75.6 %	24.66	l/yr/Hs
	Other: 100 %	Electricity	100 %	22	kWh/yr/Hs

Note: Hs – Household

3.4.2.2 Energy Demand in Economic Sectors

3.4.2.2.1 Historical Energy Demand

The historical total energy demand data were obtained from (IEA, 2022d) for Kenya. For the case of Burundi, they were determined based on different sources as follows.

The historical electric energy consumed (in GWh) by different economic sectors (between 2008 and 2018) was obtained from (ISTEEBU, 2019) and converted in TJ (Table 3.13 & Table 3.14).

Despite the huge exploitable peat deposits in Burundi, its use for cooking purposes was still difficult due to its unpleasant smell for cooking and harmful fumes from combustion (Ministry of Energy and Mining, 2011). The main clients of the National Peat Office (ONATOUR) are communities such as prisons, barracks, boarding schools and hospitals (Ministry of Energy and Mining, 2011). Therefore, the historical peat consumption was categorized under Commercial, Service and Other despite a marginal consumption by households. The historical production in tons (2008 – 2018) was found from (ISTEEBU, 2019). Hence, considering a calorific value of 14.7 MJ/kg for peat (Manirakiza et al., 2020), the historical peat consumption was then converted to TJ (Table 3.14).

Referring on the report by (Ministry of Energy and Mining, 2011), the Burundian residential sector consumes 98 % of total wood production while Industry, Agriculture and Commercial, service and other consume 1.74 %, 0.21 % and 0.04 % respectively. Hence, considering the historical wood production (2008 – 2017) obtained from (ISTEEBU, 2019), the share of wood consumption in the different sectors (converted in TJ with fuel wood calorific value of 15 GJ/ton) is presented in Table 3.12, Table 3.13 and Table 3.14.

Almost all imported oil products in Burundi are consumed by the transport sector with a marginal consumption by industry sector (African Development Bank, 2009). According to the Ministry of Water, Environment, Land Management and Urban Planning (MWELMUP) in Burundi, the Burundian energy balance showed that 93.92 % of total imported oil products were consumed by the transport sector and the remaining was shared between households (4.56 %), industry (0.18 %), agriculture (0.07 %) and Commercial, Service and Others (1.27 %) (MWELMUP, 2001). Hence, having the historical total oil products consumption in tons (2006 – 2020) obtained from annual report of The Bank of the Republic of Burundi – BRB (BRB, 2010, 2012, 2020), the consumption by different sectors were determined in TJ (Table 3.11, Table 3.12, Table 3.13 and Table 3.14). This was done by assuming that no change occurred in the share for oil products consumption.

The historical energy consumption by different sectors is presented in Table 3.11 for Transport sector, Table 3.12 for Agricultural Sector, Table 3.13 for Industrial Sector and Table 3.14 for the sector of Commercial, Service and Other.

Table 3.11: Historical Energy Consumption in TJ for Transport Sector

Year	Burundi		Kenya	
	Oil Products	Electricity	Oil products	Electricity
2000	-	0	37805	0
2001	-	0	37292	0
2002	-	0	38797	0
2003	-	0	34634	0
2004	-	0	38142	0
2005	-	0	39932	0
2006	1.90193	0	44728	0
2007	1.88046	0	45215	0
2008	2.19998	0	46672	0
2009	1.94588	0	58095	0
2010	2.89009	0	69682	0
2011	3.47581	0	64519	0
2012	3.38547	0	68511	0
2013	3.54077	0	81691	0
2014	3.75686	0	91365	0
2015	3.55959	0	113389	0
2016	3.95494	0	123809	0
2017	5.06691	0	120917	0
2018	6.46469	0	129303	0
2019	6.60016	0	132993	0
2020	7.16908	0	-	0

Table 3.12: Historical Energy Consumption in TJ for Agriculture Sector

Year	Burundi			Kenya	
	Oil Products	Electricity	Wood	Oil Products	Electricity
2000	-	0	-	3170	119
2001	-	0	-	3086	130
2002	-	0	-	2632	137
2003	-	0	-	2046	137
2004	-	0	-	2046	137
2005	-	0	-	1252	169
2006	1.90193	0	-	1252	151
2007	1.88046	0	-	2046	133
2008	2.19998	0	121.262022	1336	-
2009	1.94588	0	185.6290275	917	-
2010	2.89009	0	191.728215	1212	-
2011	3.47581	0	291.140577	1084	-
2012	3.38547	0	298.1279385	793	-
2013	3.54077	0	305.283006	1000	-
2014	3.75686	0	312.6098115	1296	-
2015	3.55959	0	320.11245	1000	-
2016	3.95494	0	327.7951425	1252	-
2017	5.06691	0	335.662236	2027	-
2018	6.46469	0	-	2108	-
2019	6.60016	0	-	907	-
2020	7.16908	0	-	-	-

Table 3.13: Historical Energy Consumption in TJ for Industry Sector

Year	Burundi			Kenya		
	Oil products	Wood	Electricity	Oil products	Coal	Electricity
2000	-	-	-	15528	2761	7549
2001	-	-	-	17862	2761	8363
2002	-	-	-	18925	4128	8820
2003	-	-	-	16917	3870	9493
2004	-	-	-	15698	4515	10120
2005	-	-	-	19841	3741	10555
2006	4.89068	-	-	24615	5005	11509
2007	4.83548	-	-	23288	4592	11776
2008	5.65710	23.097528	79.92	22522	4567	11462
2009	5.00370	35.35791	74.52	23212	3973	11999
2010	7.43165	36.51966	71.64	27771	6914	12902
2011	8.93780	55.455348	97.2	28617	9881	12920
2012	8.70551	56.786274	90.72	19819	8849	13057
2013	9.10483	58.149144	99.36	19188	12513	14515
2014	9.66050	59.544726	120.24	22569	19505	15250
2015	9.15322	60.9738	91.44	28210	20717	15602
2016	10.16983	62.43717	82.08	29658	20408	16178
2017	13.02920	63.935664	105.12	29948	19372	15760
2018	16.62348	-	150.84	30075	10965	16672
2019	16.97183	-	-	31325	63313	17026
2020	18.43477	-	-	-	-	-

Table 3.14: Historical Energy Consumption in TJ for the Sector of Commercial, Service and Other

Year	Burundi				Kenya	
	Wood	Electricity	Oil products	Peat	Oil products	Electricity
2000	-	-	-	-	777	3604
2001	-	-	-		732	4180
2002	-	-	-	-	734	4338
2003	-	-	-	-	645	4687
2004	-	-	-	-	645	5094
2005	-	-	-	-	558	5155
2006	-	-	34.50646	-	652	5594
2007	-	-	34.11698	-	881	5756
2008	993.193704	196.56	39.91397	180.6483	794	3017
2009	1520.39013	226.08	35.30387	167.1684	891	3020
2010	1570.34538	279.36	52.43444	192.7317	1078	3319
2011	2384.579964	254.16	63.06114	117.2031	1125	3632
2012	2441.809782	223.92	61.42218	288.7227	1128	3658
2013	2500.413192	276.48	64.23965	283.0632	1128	4064
2014	2560.423218	269.64	68.16019	167.2272	1740	4241
2015	2621.8734	217.44	64.58107	58.3149	1740	4295
2016	2684.79831	219.24	71.75383	140.2527	1787	4522
2017	2749.233552	207	91.92824	205.0356	2309	4637
2018	-	220.32	117.28787	173.4747	2671	4745
2019	-	-	119.74570	-	3439	4893
2020	-	-	130.06757	-	-	-

3.4.2.2.2 Trend Analysis of Energy Intensity

Based on the historical energy consumptions per sector and GDP shares of the different economic sectors, historical energy intensity levels (TJ/USD) for the various sectors were determined.

3.4.3 Energy Transformation Analysis

The transformation part of LEAP Model considers all energy conversion sectors; also called modules (SEI, 2011). This section targeted to determine required primary energy resources and imports in the countries.

Therefore, considered conversions included energy transmission and distribution, electric power generation, charcoal making, refining of oil, and coal and peat mining for Kenya and Burundi respectively.

Hence, different processes were created under each module depending on energy technology options in the countries and data of the different technologies were needed as inputs (e.g. technology efficiency, capacity factor, capacity).

3.4.3.1 Techno-economic Data for Power Plant Technologies

The overall cost for electricity generation is function of different parameters such as capital cost C (in USD/kW) of a technology *i*, installed capacity I (USD/kWh), fixed O&M cost F (in USD/kW), var. O&M cost V (in USD/kWh) and consumed electricity E (kWh). The total generation cost C_T (in USD) is given by Eq. 0.2 (Liya & Jianfeng, 2018).

$$C_T = \sum_i^n C_i \times I_i + F_i \times I_i + V_i \times E_i \tag{3.12}$$

Therefore, the costs for existing power plants technologies and new planned technologies in the countries were considered in this study. Techno-economic data for different power generation technologies were taken from the various sources (EURELECTRIC, 2003; J. de D. K. Hakizimana et al., 2016; IRENA, 2012a, 2015; Lazard, 2017, 2020; Murphy et al., 2015; Z. Biserčić & S. Bugarić, 2021). The average values, from the ranges presented Table 3.2 and Table 3.3 were compared to the values ranges provided by Allington et al. (Allington et al., 2022) for Africa. They were then found within the ranges (almost similar) and were validated to be used in this study. Table 3.15 presents the techno-economic data for different power plants technologies.

Table 3.15: Techno-economic Data for Power Supply Technologies

Technologies	Plant lifetime (Years)	Capital cost (USD/kW)	Fixed O&M cost (USD/kW-yr)	Var. O&M cost (USD/MWh)	Efficiency (%)	Capacity factor (%)
Hydro	50	3000	40	2.0	92.5	52.5
PV – Utility	24	900	11.5	–	15	27.5
CSP – with storage	30	7545	77.5	–	18.5	53.5
Wind – Onshore	25	1250	33.25	–	35	46.5
Geother.	25	5275	13.5	16.5	15	85
Biomass	30	2850	50	10	35	82.5
NG – CCGT	30	975	16.5	3.9	58	60
Oil-centralized diesel	25	650	10	10	41	52.5
Coal	35	4562.5	61.4	3.9	43	73
Peat	30	2010	23	4	37.5	91
Nuclear	50	6137	184	10.5	33	85

Capacities for current and planned power plants are detailed in the following sections. The planning reserve margin (PLM) is then determined as Eq. 0.3 and Eq. 0.4 (SEI, 2011):

$$PRM\,(\%) = {100 \times (Module\ Capacity - Peak\ Load)} \Big/ {Peak\ Load} \qquad (3.13)$$

$$Module\ Capacity = \sum_i (Capacity * Capacity\ Value) \ \ ; i = All\ \ Processes\ in\ the\ Module \qquad (3.14)$$

For electricity generation, different processes were examined with an intention to investigate how they are dispatched to meet annual energy demand as well as instantaneous power demand. Therefore, it was necessary to determine the system load curve for each of the countries and the different processes were dispatched by merit order (Table 3.16).

Table 3.16: Power Supply Technologies Dispatch Rules

Dispatch rules	Description
Process Share	Process dispatched to meet a specified percentage fraction of a module requirements
In Proportion to Available Capacity	Process dispatched proportionally to its available capacity to meet module requirements
Run to Full Available Capacity	Process dispatched to produce its maximum available capacity regardless the module requirements
In Ascending Merit Order	Process dispatched to meet yearly energy demand as well as instantaneous power demand
In Ascending Order of Running Cost	In ascending order and addition to merit order rule, processes are dispatched in its total running cost

Source: (SEI, 2011)

The Peat, Coal, Nuclear and RE plants were set with merit order 1 (dispatched to meet Base load) while other fossil fuels (Oil and NG) plants were set with merit order 2 (dispatched to meet Peak load).

The system load curve was determined based on monthly peak load, presented in MW for Kenya (Ministry of Energy Report, 2019) and monthly peak load, presented in monthly energy generation for Burundi (REGIDESO, 2016)) as presented in Appendix. The system load shape was determined as fraction of the annual peak load with a year divided into 12 time-slices (no daily and hourly detail).

For electricity generation, the first simulation year was set to “first scenario year” where LEAP simulated the model from the year 2016 considering historical production data in 2015.

For charcoal making, process was dispatched with the rule “Percentage Share”.

The process for oil refining was dispatched with the rule “Percentage Share”. The first simulation year was set to “base year” where LEAP simulated the model from the year 2015.

The processes for coal and peat mining were dispatched with the rule "Percentage Share". The first simulation year was set to "base year" where LEAP simulated the model from the year 2015.

As none of the modules was set to « Run to Full Capacity" dispatch rule, this means that all the processes will try to meet the condition: "*Total required domestic energy + Exports targeted – Minimum Imports*". Therefore, for shortfall rule, all output fuels were set to "Import to meet shortfall" in case domestic productions would be lower than the total required energy while the surplus rule was set to "Surplus Exported". For all the modules, the usage rule is "Domestic Priority".

3.4.3.2 Energy Transformation Modelling

3.4.3.2.1 Transmission and Distribution

The historical total losses data for the countries (technical and commercial losses from electricity supply) were obtained from the development Indicators of the World Bank data & (Government of Kenya, 2018; The Kenya Power and Lighting Company, 2019) for Kenya and World Bank data & REGIDESO for Burundi. In Burundi, losses of the transmission and distribution were 30 %, 26 %, 23 % and 19 % in 2006, 2007, 2008, 2009 and 2010 respectively (International Monetary Fund, 2012) while they were 21.67 % and 18.75 % in 2010 and 2011 respectively (Ministry of Energy and Mining, 2013). Table 3.17 shows the historical data of total energy losses for Burundi and Kenya.

Table 3.17: Historical Data of Total Energy Losses for Burundi and Kenya

Year	Burundi		Kenya	
	Total Losses (GWh)	Total Losses (%)	Total Losses (GWh)	Total Losses (%)
2000	-	-	-	21.6425362
2001	-	-	-	20.9348693
2002	-	-	-	22.65003227
2003	-	-	-	20.87845969
2004	-	-	-	18.0294282
2005	-	-	-	18.9836348
2006	44.9	30	-	17.58521822
2007	50.5	26	-	16.39141843
2008	46.8	23	-	16.06382979
2009	38.3	19	-	15.76383764
2010	52,3	21.67	-	15.95888558
2011	46,0	18.75	-	17.13733075
2012	59.327 *	24.1*	1,507	18.45230807
2013	64.566*	24.5*	1,506	17.98107256
2014	39.662*	15.0*	1,624	17.55238712
2015	74.057*	28.8*	1,905	19.4
2016	79.134 *	27.5*	1,932	18.9
2017	70.975*	27.4*	2,244	21.0
2018	98.837*	31.3*	2,724	23.7

*Source: REGIDESO (REGIDESO, 2022)

Therefore, for the base year, the losses were set to 28.8 % and 19.4 % for Burundi and Kenya respectively. The historical transmission and distribution losses seemed to have a slight declining trend for both countries. Figure 3.9 shows the historical trend of total energy losses (%) for Burundi and Kenya.

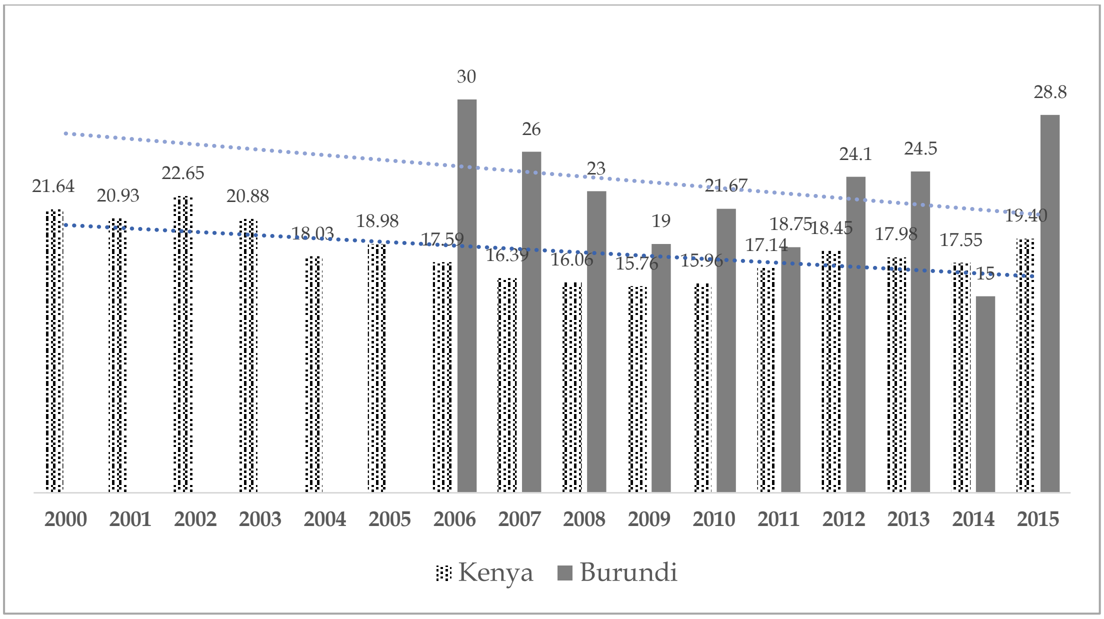


Figure 3.9: Historical Trend of Total Energy Losses (%) for Burundi and Kenya

Therefore, this reference scenario estimated the losses to follow the figures of Table 3-18 estimated by (Allington et al., 2022; Pappis, I., Howells, M., Sridharan, V., Usher, W., Shivakumar, A., Gardumi, F., Ramos, 2019). Techno-economic data for power transmission and distribution in terms of efficiency (referring to power losses during transmission and distribution) and capital cost (needed for a new construction) are presented in Table 3.18.

Table 3.18: Projected Efficiencies (%) and Economic ($/kW) Data for Power Transmission and Distribution for Burundi and Kenya

Year	Burundi			Kenya		
	Efficiency	Capital cost ($/kW)	Lifetime (years)	Efficiency	Capital cost ($/kW)	Lifetime (years)
2020	86.5 %	365* – 2502**	50* –70**	81.7 %	365* – 2502**	50* –70**
2030	87.4 %		50* –70**	83.6 %		50* –70**
2050	89.3 %		50* –70**	88.4 %		50* –70**

*Transmission, ** Distribution

3.4.3.2.2 Electric Power Generation

This module considers all the existing and planned power plants for construction in these countries. Data for yearly peak power and energy generation were obtained from

(Government of Kenya, 2018; Ministry of Energy, 2018; The Kenya Power and Lighting Company, 2019) for Kenya and from REGIDESO (EAC, 2021b; REGIDESO, 2022) for Burundi. They are presented in Table 3.19.

Table 3.19: Historical Local Electric Power Supply Data for Burundi and Kenya

Year	Burundi				Kenya							
	Demand (MWh)	Peak (MW)	Generation (GWh)		Demand	Peak	Generation (GWh)					
			H	Therm.	(MWh)	(MW)	H	G	Oil	W	S	Bio
2000	-	-	-	-	-	-	1325	429	2124	-	-	133
2001	147010.00	-	114.60	0	3489800	-	2403	480	1508	-	-	115
2002	157300.00	-	127.30	0	3742000	-	3119	386	1022	-	-	145
2003	168310.00	-	101.50	0	3910400	-	3433	498	920	-	-	135
2004	180090.00	-	91.00	0	4234100	-	3169	987	1038	-	-	150
2005	192690.00	-	100.30	0	4498395.72	-	3039	1002	1506	-	-	163
2006	206180.00	-	92.00	0	4752400	-	3025	1046	1819	-	-	162
2007	192618.00	-	117.00	0	5157000	-	3592	989	1736	-	-	176
2008	160284.00	-	111.79	0	5352200	1044	3267	1039	2145	-	-	168
2009	168653.00	-	120.00	6.00	5428700	1072	2160	1293	2997	7	-	279
2010	189812.00	-	142.00	17.00	5754730	1107	3224	1057	2586	17	3	270
2011	246000.00	-	141.00	12.00	6273600	1194	3183	1444	2801	18	6	270
2012	237887.00	49.50	139.00	3.00	6414400	1236	3977	1516	2200	14	12	258
2013	259291.00	53.20	154.00	8.00	6928100	1354	4386	1781	2162	15	27	271
2014	264923.00	57.50	168.00	8.00	7768600	1468	3410	2917	2585	17	49	220
2015	266407.00	54.25	134.00	3.00	7826400	1512	3463	4521	1412	60	50	230
2016	286862.00	53.40	143.00	24.00	8053200	1586	3960	4484	1470	56	60	229
2017	254856.00	59.50	99.80	73.80	8410100	1656	2777	4756	2534	61	73	157
2018	313743.00	59.90	133.20	99.00	8702300	1802	3986	5128	1446	375	90	169
2019	309683.00	62.93	-	-	8854000	1882	3205	5235	1313	1563	92	148
2020	-	-	-	-	8796400	-	4233	5060	754	1331	88	148

The installed capacities for different power plants were obtained from (EAC, 2021b; Energy & Petroleum Regulatory Authority, 2020; KNBS, 2016, 2021) for Kenya and from (EAC, 2021b) for Burundi. These data are presented in Table 3.20.

Table 3.20: Historical Dependable Installed Capacities of Power Plants (in MW)

Year	Burundi			Kenya					
	H	Th -Oil	Bag	H	S	W	G	Bag	Therm
2000	-	-	-		-	-		-	
2001	30.2	-	-	677	-	-	58	-	407
2002	32	-	-	677	-	-	58	-	407
2003	32	-	-	677	-	-	58	-	407
2004	32	-	-	677	-	-	128	-	393
2005	32	-	-	677	-	-	128	-	351
2006	32	-	-	677	-	-	128	2	370
2007	32	-	-	677	-	-	128	2	390
2008	32	5.5	-	719	-	-	128	2	419
2009	32	5.5	-	730	-	-	158	2	421.5
2010	32	5.5	-	728	-	-	189	26	469.2
2011	32	6	4	763.2	-	5.3	198.0	26	660.5
2012	32	20	4	788.4	-	5.4	209.5	26	660.6
2013	32	20	4	812.3	-	5.9	241.8	26	714.4
2014	32	20	4	818.3	-	26.3	573.4	26	751.3
2015	32	20	4	820.4	0.6	26.1	627.0	26	833.6
2016	-	-	-	818.7	0.6	26.1	652.0	28	801.6
2017	*48	14+20	-	826.2	0.55	26.1	652.0	28	806.9
2018	*48	*14+20	-	826.2	50.7	336.1	663.0	28	807.7
2019	*48	*14+20	-	828.4	51	336	828.4	28	749.3
2020	*48	*14+20	-	834	52.5	336.1	863.1	28	749.1

*****(The World Bank, 2019b)

Kenya imports electricity from three main electric power companies: UETCL (Uganda Electricity Transmission Company Limited) from Uganda, TANESCO (Tanzania Electricity Supply Company Limited) from Tanzania and EEPCo (Ethiopian Electric Power Corporation) from Ethiopia while Burundi imports its electricity from the International Electricity Company of the Great Lakes Countries (RUZIZI II – SINELAC) and the National Society for Electricity – DRC (RUZIZI I – SNEL). In the same time, Kenya has been exporting its electricity the same companies (Government of Kenya, 2018; Ministry of Energy, 2018; The Kenya Power and Lighting Company, 2019). The yearly electric energy imported and exported was obtained from (EAC, 2021b) in both countries. Table 3.21 shows the yearly importation-exportation between 2000 and 2020.

Table 3.21: Historical Electricity Imports-Exports (in MWh) for Burundi and Kenya

Year	Burundi		Kenya	
	Importation	Exportation	Importation	Exportation
2000	-	-	-	-
2001	40565	9148	113700	-
2002	40257	10174	238400	-
2003	57027	1019	189400	-
2004	72608	211	161900	-
2005	71206	46	27900	24400
2006	58160	39	10800	46700
2007	-	-	-	-
2008	96157	2	25000	41000
2009	85036	-	39000	27000
2010	99436	4	30000	29600
2011	104121	-	33900	37300
2012	104289	-	39100	32700
2013	111589	7	49000	43700
2014	89368	23	158400	30800
2015	91689	-	58800	36700
2016	119958	-	86300	39100
2017	85240	-	229600	12256
2018	83729	-	130300	35195
2019	81993.41	-	212000	16200
2020	83762.08	-	136700	16500

Source: (EAC, 2021b)

Since there are many electric power plants planned for construction throughout the study period for both countries, planned power plants expected to be commissioned (in future) were considered in reference scenario.

For Burundi, about 400 MW power plants were planned to increase its total power supply by 2024 (Nsabimana, 2020). However, their commissions were delayed and they were expected to go beyond the planned years. For instance, the RUSUMO Falls hydropower plant projected was expected to be commissioned by 2021 (Nsabimana, 2020) and this was not yet complete as of February 2023. Therefore, the updated commission years were obtained from REGIDESO for the projects Kagunuzi, Kabu 16, Mulembwe Jiji and Ruzizi III while others were shifted away from their initial plans to 3 years (Rusumo Falls) and 4 years for others apart from Ruzibazi hydropower plant which was complete by 2022. Other future projects were found in Burundian plan for 2017 – 2040 production capacity (The World Bank, 2019b). Similarly, Kenya has planned its generation expansion model and imported coal fuels were expected to be contribute to the power generation (Government of Kenya, 2018)**.** Table 3.22 shows the expansion plans for Kenya and Burundi.

Table 3.22: Future Planned Expansion of Power Plants (in MW) for Burundi and Kenya

Year	Burundi							Kenya											
	Plant	H	S	DE	B	P	I	Plant	H	S	W	Geo	B/C	NG	Nu	DE	C	I	GO
2018	-	-	-	-	-	-	-	OrPower4 Plant 1 Additional Lake	-	-	-	10	-	-	-	-	-	-	-
								Lake Turkana - Phase I, Stage 1	-	-	100	-	-	-	-	-	-	-	-
								Strathmore	-	0	-	-	-	-	-	-	-	-	-
2019	-	-	-	-	-	-	-	HVDC Ethiopia	-	-	-	-	-	-	-	-	-	400	-
								Olkaria 5	-	-	-	158	-	-	-	-	-	-	-
								Olkaria Modular	-	-	-	50	-	-	-	-	-	-	-
								Back-up capacity 80 MW - Unit 2	-	-	-	-	-	-	-	-	-	-	80*
								Olkaria 1 - Unit 1 Rehabilitation	-	-	-	17	-	-	-	-	-	-	-
								Lake Turkana - Phase I, Stage 2	-	-	100	-	-	-	-	-	-	-	-
								Lake Turkana - Phase I, Stage 3	-	-	100	-	-	-	-	-	-	-	-
								PV grid Garissa	-	50	-	-	-	-	-	-	-	-	-
								Marcoborero	-	2		-	-	-	-	-	-	-	-
								Kopere	-	40	-	-	-	-	-	-	-	-	-
2020	-	-	-	-	-	-	-	Menengai 1 Phase I - Stage 1	-	-	-	103	-	-	-	-	-	-	-
								Olkaria 1 - Unit 6	-	-	-	70	-	-	-	-	-	-	-
								Back-up capacity 80 MW - Unit 3	-	-	-	-	-	-	-	-	-	-	80*
								Olkaria 1 - Unit 2 Rehabilitation	-	-	-	17	-	-	-	-	-	-	-
								Olkaria 1 - Unit 3 Rehabilitation	-	-	-	17	-	-	-	-	-	-	-
								Kipeto - Phase I	-	-	50	-	-	-	-	-	-	-	-
								Kipeto - Phase II	-	-	50	-	-	-	-	-	-	-	-
								Alten, Malindi, Selenkei	-	20	-	-	-	-	-	-	-	-	-
								Quaint, Kenergy	-	50	-	-	-	-	-	-	-	-	-
2021	-	-	-	-	-	-	-	Olkaria Topping	-	-	-	47	-	-	-	-	-	-	-
								Ngong 1 - Phase III	-	-	10	-	-	-	-	-	-	-	-
								Chania Green	-	-	50	-	-	-	-	-	-	-	-
								Aperture	-	-	50	-	-	-	-	-	-	-	-

								Eldosol	-	40	-	-	-	-	-		-	-	-
								Makindu Dafre rAREH	-	30	-	-	-	-	-	-	-	-	-
								Gitaru Solar	-	40	-	-	-	-	-	-	-	-	-
2022	Ruzibazi	15	-	-	-	-	-	Olkaria 6 PPP	-	-	-	140	-	-	-	-	-	-	-
								Menengai I - Stage 2	-	-	-	60	-	-	-	-	-	-	-
								Prunus	-	-	51	-	-	-	-	-	-	-	-
								Meru Phase I	-	-	80	-	-	-	-	-	-	-	-
								Ol-Danyat Energy	-	-	10	-	-	-	-	-	-	-	-
								Electrawinds Bahari	-	-	50	-	-	-	-	-	-	-	-
								Hanan, Greenmillenia, Kensen	-	90	-	-	-	-	-	-	-	-	-
2023	-	-	-	-	-	-	-	Olkaria 7	-	-	-	140	-	-	-	-	-	-	-
								Eburru 2	-	-	-	25	-	-	-	-	-	-	-
								GDC Wellheads	-	-	-	30	-	-	-	-	-	-	-
								OrPower4 Plant 4 Additional	-	-	-	61	-	-	-	-	-	-	-
								Wellhead Leasing	-	-	-	50	-	-	-	-	-	-	-
								Karura	89	-	-	-	-	-	-	-	-	-	-
								Electrawinds Bahari Phase 2	-	-	40	-	-	-	-	-	-	-	-
								Sayor, Izera, Solarjoule	-	30	-	-	-	-	-	-	-	-	-
								Belgen, Tarita Green Energy Elgeyo	-	80	-	-	-	-	-	-	-	-	-
2024	Jiji-Mulembwe	49.5	-	-	-	-	-	Lamu Unit 1	-	-	-	-	-	-	-	-	327	-	-
	Imports from Ethiopia	-	-	-	-	-	200	Lamu Unit 2	-	-	-	-	-	-	-	-	327	-	-
								Lamu Unit 3	-	-	-	-	-	-	-	-	327	-	-
								Olkaria 8	-	-	-	140	-	-	-	-	-	-	-
	Solar projects	-	7.5	-	-	-	-	Menengai III	-	-	-	100	-	-	-	-	-	-	-
								Baringo Silali - Paka I	-	-	-	100	-	-	-	-	-	-	-
								Marine Power Akiira Stage 1	-	-	-	70	-	-	-	-	-	-	-
								Meru Phase II	-	-	100	-	-	-	-	-	-	-	-
	Kabu 16	20	-	-	-	-	-												
								Tarita Isiolo, Kengreen	-	50	-	-	-	-	-	-	-	-	-
	Rusumo Falls	26.6	-	-	-	-	-	Asachi, Astonfield Sosian, Sunpower	-	81	-	-	-	-	-	-	-	-	-
2025	Mpanda Hydro	10.4	-	-	-	-	-	AGIL Longonot Stage 1	-	-	-	70	-	-	-	-	-	-	-
	Peat Power Project	-	-	-	-	15	-												
								Olsuswa 140MW unit 1 & 2	-	-	-	140*	-	-	-	-	-	-	-
	Therma**	-	-	40	-	-	-												
	Solar PV**	-	19	-	-	-	-	Meru Phase III	-	-	220	-	-	-	-	-	-	-	-
2026	Ruzizi III	49	-	-	-	-	-	Suswa I	-	-	-	100	-	-	-	-	-	-	-
	Kagu 006	8	-	-	-	-	-	Baringo Silali - Silali I	-	-	-	100	-	-	-	-	-	-	-
								Aeolus Kinangop	-	-	60	-	-	-	-	-	-	-	-
								Solargen	-	40	-	-	-	-	-	-	-	-	-

2027	-	-	-	-	-	-	-	Baringo Silali - Korosi I	-	-	-	100	-	-	-	-	-	-	-
2028	-	-	-	-	-	-	-	Menengai IV	-	-	-	100	-	-	-	-	-	-	-
								Marsabit Phase I - KenGen	-	-	300	-	-	-	-	-	-	-	-
2030	Therma**	-	-	120	-	-	-	Olkaria 9 & other fields	-	-	-	420	-	-	-	-	-	-	-
	Biomass				35			Suswa II	-	-	-	100	-	-	-	-	-	-	-
2031	-	-	-	-	-	-	-	Menengai V	-	-	-	100	-	-	-	-	-	-	-
								High Grand Falls Stage 1	495	-	-	-	-	-	-	-	-	-	-
2032	-	-	-	-	-	-	-	High Grand Falls Stage 1+2	693	-	-	-	-	-	-	-	-	-	-
2033	-	-	-	-	-	-	-	Suswa III	-	-	-	100	-	-	-	-	-	-	-
2035	-	-	-	-	-	-	-	Dongo Kundu CCGT - small 1	-	-	-	-	-	375	-	-	-	-	-
2036	-	-	-	-	-	-	-	Dongo Kundu CCGT - small 2	-	-	-	-	-	375	-	-	-	-	-
								Nuclear Unit 1 u63	-	-	-	-	-	-	600	-	-	-	-
2037	-	-	-	-	-	-	-	Nuclear Unit 2	-	-	-	-	-	-	600	-	-	-	-
2040	Therma**	-	-	244	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hydro**	194	-	-	-	-	-												
	Solar PV**	-	204	-	-	-	-												
	Bioma**	-	-	-	65	-	-												

GO: Gasoil; I: Imports; P: Peat; NG: Natural gas (using LNG import); Nu: Nuclear; DE: Diesel Engines; C: Coal (import); S: Solar PV; H: Hydropower; W: Wind; B/C: Biomass/Cogeneration

* Generic back-up capacity

** Total installed capacity in the specified year (not additional capacity)

Some power plants were expected to be retired during the study period. Therefore, plants expected to be decommissioned were also considered for power generation in the reference scenario. For Kenya, a total capacity of 1091 MW made of various power plants was expected to be out of service by 2040 (Government of Kenya, 2018) while 10 MW from thermal power plant and 4MW from hydropower plant were expected to be decommissioned by 2030 and 2040, respectively (The World Bank, 2019b). Table 3.23 summarizes the expected power plants to be decommissioned by 2040.

Table 3.23: Planned Decommissioning of Power Plants (Net capacity in MW) for Burundi and Kenya

Year	Burundi		Kenya				
	Hydro	DE	Plant	Wind	Geothermal	GT (gasoil)	DE
2019	-	-	Olkaria 1 - Unit 1	-	15	-	-
			Olkaria 1 - Unit 2	-	15	-	-
			Iberafrica 1	-		-	56
2020	-	-	Olkaria 1 - Unit 3	-	15	-	-
2021	-	-	Embakasi GT 1	-	-	27	-
			Embakasi GT 2	-	-	27	-
			Tsavo	-	-	-	74
2023	-	-	Kipevu 1	-	-	-	60
2028	-	-	Ngong 1, Phase I	5	-	-	-
2029	-	-	Orpower4 Plant1 (Olkaria 3 - Unit 1- 6)	-	48	-	-
2030	-	10	Rabai Diesel (CC-ICE)	-	-	-	90
2031	-	-	Kipevu 3	-	-	-	115
2033	-	-	Olkaria 2	-	105	-	-
2034	-	-	OrPower4 Plant 2&3 (Olkaria 3 - Unit 7-9)	-	62	-	-
			Iberafrica 2	-	-	-	53
			Thika (CC-ICE)	-	-	-	87
			Athi River Gulf	-	-		80
2035	-	-	Triumph (Kitengela)	-	-	-	83
			Ngong 1, Phase II	20	-	-	-
2036	-	-	KenGen Olkaria Wellheads I & Eburru	-	55	-	-
2040	4	-	-	-	-	-	-

Note: DE: Diesel Engine ; GT: Gas Turbine

However, some projects were not implemented for the years 2016 to 2020 and this has caused some discrepancies between planned capacities expansion and real capacities. Therefore, data for planned capacities expansion were considered as from the year 2021 and real capacities were taken for the years 2015 – 2020. For instance, installed geothermal capacity was 663 MW in 2018 and 828 MW in 2019 (EAC, 2021b). The planned expansion was 225 MW (158 MW from Olkaria 5 Power plant, 50 MW from Olkaria Modular and 17 MW from Olkaria 1 - Unit 1 Rehabilitation) (Government of Kenya, 2018)**.** While 30 MW of capacity (15 MW from Olkaria 1 - Unit 1 and 15 MW from Olkaria 1 - Unit 2) were supposed to be decommissioned in 2019 (Government of Kenya, 2018), this would make a 873 MW of total geothermal installed capacity in 2019.

3.4.3.2.3 Charcoal Production

On average, Kenya produces between 1.6 – 2.4 million tons of charcoal per year (Njenga et al., 2013) while the annual production is between 0.17 – 0.2 million tons in Burundi (ISTEEBU, 2019). About 99 % of consumed charcoal in Kenya is produced using Traditional Earth Mound Kilns which has a low efficiency of maximum 20 % (Njenga et al., 2013). This low conversion efficiency would reach 45 % by using more efficient kilns (Njenga et al., 2013) such Brick Beehive Kilns. These unimproved kilns are most preferred by charcoal producers as they are cheap and easy to construct (Njenga et al., 2013).

Therefore, the base year assumed that the remaining share (1 %) is produced though improved kilns in Kenya. The energy transformation assumed that no charcoal is imported or exported in both countries. The used charcoal is all domestically produced by conversion from wood using Traditional Earth Mound in Burundi. By considering the heating value of 31 GJ/ton (conversion efficiency: 0.31) for charcoal (Ministry of Energy, 2019), the annual charcoal consumption was converted to charcoal annual energy capacities in the both countries. As there is no clear policy regarding improved kilns in both countries, the reference scenario assumed that no significant change is expected in adopting improved kilns and 2 % of adoption was assumed for Burundi against 4 % for Kenya in every 10 years as from 2020 (Table 3.24).

Table 3.24: Expected Adoption (%) of Charcoal Production Kilns Technologies in Burundi and Kenya

Year	Burundi		Kenya	
	Traditional Earth Mound Kilns	Brick Beehive Kilns	Traditional Earth Mound Kilns	Brick Beehive Kilns
2015	99 %	1 %	99 %	1 %
2020	99 %	1 %	99 %	1 %
2030	98 %	2 %	95 %	5 %
2040	96 %	4 %	91 %	9 %

3.4.3.2.4 Oil Refining

The refinery helps to transform crude oil (imported or locally produced) into useful oil products (e.g. gasoline, diesel). The O&M costs for the refinery activities were obtained from (Allington et al., 2022). The data for two types of refinery technologies (Heavy Fuel Oil – HFO and Light Fuel Oil – LFO) are presented in Table 3.25.

Table 3.25: Refinery Type Technologies and Associated Techno-economic Data

Technology	Capital Cost ($/kW in 2020)	Variable Cost ($/GJ in 2020)	Operational Life (years)	Output Ratio
Crude Oil Refinery Option 1	24.1	0.71775	35	0.9 LFO: 0.1 HFO
Crude Oil Refinery Option 2	24.1	0.71775	35	0.8 LFO: 0.2 HFO

Kenya previously had a refinery of crude oil which had an annual capacity of 1.6 million metric tons before it stopped in 2013 (Energy & Petroleum Regulatory Authority, 2020; IEA, 2022c; Simbiri, 2022). The government had an intension to upgrade the annual capacity of its refinery to 4 million metric tons (Simbiri, 2022). However, as of February 2019, the Kenyan government has declared its willingness to construct a local refinery to process and wishes instead to export the locally discovered oil and import refined oil products (Simbiri, 2022). Burundi does not have any oil refinery facility and this country imports all its refined oil from other countries, especially from Kenya and Tanzania (UNEP, n.d.).

Therefore, the reference scenario assumed that there will not be any refinery of crude oil in the two countries in future.

3.4.3.2.5 Coal and Peat Mining

Currently, Kenya imports a significant amount of coal fuels used especially for industrial activities. For the case of Burundi, peat is locally extracted in the country. Table 3.26 shows historical importations (Kenya and Burundi) and exportations (Kenya) of oil products and NG in these countries. The process of peat mining was considered with efficiency of 37.5 %.

Table 3.26: Historical Imports-Exports of Peat (in TJ) for Burundi and Coal (in TJ) for Kenya

Year	Burundi (Peat)		Kenya (Coal)	
	Import	Export	Import	Export
2000	0	0	2761	0
2001	0	0	2761	0
2002	0	0	4128	0
2003	0	0	3870	0
2004	0	0	4515	0
2005	0	0	3741	0
2006	0	0	5005	0
2007	0	0	4592	0
2008	0	0	4567	0
2009	0	0	3973	0
2010	0	0	6914	0
2011	0	0	9881	0
2012	0	0	8849	0
2013	0	0	12513	0
2014	0	0	19505	0
2015	0	0	20717	0
2016	0	0	20408	0
2017	0	0	19372	0
2018	0	0	17737	0
2019	0	0	15222	0
2020	-	-	-	-

Source: for Burundi (ISTEEBU, 2019) and Coal (in TJ) for Kenya (IEA, 2022d)

3.4.3.2.6 Key Assumptions for Reference Scenario

The reference scenario for energy supply was built based on government plans for these countries. The projected power plants to be constructed were found from the "Updated least cost power development plan: 2017 – 2037" (Government of Kenya, 2018) for Kenya and from different reports (Nsabimana, 2020; REGIDESO, 2022; The World Bank, 2019a, 2019b) for the case of Burundi. The coal mining and oil refining were not considered in this study as there was no information on when these resources are expected to be exploited. For instance, all projected coal fuelled power plants in Kenya (Lamu Unit 1, Lamu Unit 2 and Lamu Unit 3) are expected to be fuelled by imported coal (Government of Kenya, 2018). In addition, the Kenyan government has already shown interest where to export all the locally discovered oil and import refined oil products for the domestic demand (Simbiri, 2022). For the case of Burundi, peat mining was considered in this study and all the demand for oil produced is satisfied by the importation of refined oil. In the both countries, charcoal and firewood demand was considered to be satisfied by local resources.

3.5 Alternative Energy Policies Formulation: Scenario Design and Modelling

The alternative energy policy scenarios were projected to target four main future policy alternatives: Efficient Lighting, Universal Electrification, Efficient Cooking Stoves and Climate Smart Scenario: Low-Emissions. These alternatives were selected for evaluation as they were found to be key priorities for implementation by the respective governments in both countries. They are found in several published strategy reports such as: Kenyan National Energy Policy (Ministry of Energy, 2018); Kenya Household Cooking Sector Study (Ministry of Energy, 2019); Kenya National Electrification Strategy (Republic of Kenya, 2018); Country Priority Plan and Diagnostic of the Electricity Sector (AfDB, 2021); Kenya National Energy Efficiency and Conservation

Strategy (Ministry of Energy, 2020) for Kenya and An Infrastructure Action Plan for Burundi aiming at accelerating regional integration (African Development Bank, 2009); Strategy Elaboration for the Burundian Energy Sector (Ministry of Energy and Mining, 2011); Support Burundian Households to Decrease their consumption of Energy (Aera, 2021); National Program for Energy Efficiency (Ministry of Energy and Mining, 2015) ; Burundi Sustainable Energy for All (Ministry of Energy and Mining, 2013) for Burundi. The first two ones are in line with demand side management. The last scenario was selected as it seemed to be of interest at national and international levels due to many agreements such Paris Agreement to reduce CO_2 emissions.

Therefore, this research sought to explore the effect of these policies in order to provide useful insights to the countries' policymakers.

3.5.1 Efficient Lighting

This policy sought to find how energy used for lighting would be reduced in these countries. Electricity consumption was found to have a significant share in residential sector in Burundi (Ministry of Energy and Mining, 2015) as well as Kenya and is mostly used for lighting. Therefore, a rapid penetration of efficient lighting would play an important role in energy saving of these countries since efficient lamps such as compact fluorescent lamps are able to save about 70 % (Khan & Abas, 2011) as compared to electric bulbs.

In Kenya, the national target to improve energy efficiency expects that 100 % of electrified households will be using efficient lamps by 2030 (Ministry of Energy, 2020). Therefore, the efficient lighting scenario assumed the efficient lighting availability of 65 % and 40 % for the electrified urban and rural households by 2025 and 100 % by 2030.

As the Burundian grogram for energy efficiency targeted to have distributed about 400,000 efficient lamps by 2022 (Ministry of Energy and Mining, 2015), therefore, this scenario assumed an annual increase by 3 % and 2 % in urban and rural respectively from 2015 to 2025 and rapid increase in trying to reach 70 % in urban and 60 % in rural households by 2030 before reaching 100 % by 2040. Table 3.27 summarizes the efficient lighting scenario for the both countries.

Table 3.27: Efficient Lighting Penetration (%) as per Electrified Households in Burundi and Kenya

Year	Burundi		Kenya	
	Urban Households	Rural Households	Urban Households	Rural Households
2015	10 %	16 %	11.4 %	3.5 %
2025	40 %	36 %	65 %	40 %
2030	70 %	60 %	100 %	100 %
2040	100 %	100 %	100 %	100 %

3.5.2 Efficient Cooking Stoves

The wood fuels are the main source of energy for cooking in these EAC countries and this was expected to remain the principal source in future. While there is a low adoption of improved wood fuel cooking -stoves in Kenya (Ministry of Energy, 2019) as well as in Burundi (Ministry of Energy and Mining, 2011), the quantities of biomass fuels used for cooking depend on cook-stoves efficiencies. Therefore, a rapid adoption of efficient cooking stoves would save a significant amount energy and hence reduce the quantity of wood used and greenhouse emissions.

The Kenyan energy efficiency policy expected that 57.6 % of Kenyans will own improved cooking stoves by 2027 against 57.7 % by 2030 (Ministry of Energy, 2019). Therefore, this scenario assumed a penetration of 40 %, 70 %, 50 % and 80 % for electrified urban households, non-electrified urban households, electrified rural households and non-electrified rural households by 2030, respectively. This will continue and is expected to reach 70 %, 90 %, 80 % and 100 % for electrified urban households, non-electrified urban households, electrified rural households and non-electrified rural households by 2040, respectively.

In Sustainable Energy for All "SE4All" program, the Burundian government expected that 50 % and 100 % of households will be using improved cooking stoves by 2020 and 2030 respectively (Ministry of Energy and Mining, 2013). Therefore, this policy assumed a penetration of 40 % and 50 % for urban households and rural households by 2025, respectively. In the following years, the penetration is expected to continue and reach 100 % for all households' categories by 2030.

Table 3.28 and Table 3.29 highlight the rate of penetration of cooking stoves technologies in the efficient cooking stoves scenario.

Table 3.28: Efficient Firewood Cooking Stoves Technologies Penetration (%) in Burundi and Kenya

Households	Burundi			Kenya		
Category	2015	2025	2030	2015	2030	2040
Rural households	0	50	100	32*, 30**	80*, 50**	100*, 80**
Urban households	0	40	100	8.9*, 3.5**	70*, 40**	90*, 70**

*Non-electrified, **Electrified

Table 3.29: Efficient Charcoal Cooking Stoves Technologies Penetration (%) in Burundi and Kenya

Households	Burundi			Kenya		
Category	2015	2025	2030	2015	2030	2040
Rural households	2.51	50	100	5.95*, 12**	80*, 50**	100*, 80**
Urban households	0.13	40	100	7.62*, 11**	70*, 40**	90*, 70**

*Non-electrified, **Electrified

3.5.3 Universal Electrification

In base year case (2015), the Kenyan electrification rate was 78.1 % in urban area against 29 % in rural area while it was 57.1 % in urban area and 1.7 % in rural area for

Burundi (The World Bank, 2022). These rates became 94 % in urban area against 62.7 % in rural area for Kenya in 2020 and 63.7 % in urban area against 3.5 % in rural area for Burundi (The World Bank, 2022).

This policy assumes a rapid increase in electrification rate of both countries. In Kenya, it is assumed that 100 % of urban households will be electrified by 2025 while 80 % of rural households will be electrified by 2025 before they become fully electrified by 2030. For the case of Burundi, in view of the action plan to accelerate regional integration (African Development Bank, 2009), this scenario expects that 85 % of urban households will be electrified by 2030 before a full electrification by 2040 while 34 % of rural households will be electrified by 2030 against 100 % by 2040. Table 3.30 shows the universal electrification targets (%) in the two countries.

Table 3.30: Universal Electrification (%) in Burundi and Kenya

Households	Burundi			Kenya		
Category	2020	2030	2040	2020	2025	2030
Urban electrified	63.7 %	85 %	100 %	94 %	100 %	100 %
Rural electrified	3.5 %	34 %	100 %	62.7 %	80 %	100 %

3.5.4 Climate Smart Scenario: Low – Emissions

In this policy scenario, a high deployment of renewable energy technologies was considered. This policy explored the impact of the full potential of RE technologies in these countries on their energy system. The aim was to reduce the greenhouse emissions by a rapid implementation of RE power plants while declining fossil fuels-based power plants. With this policy, the Burundian Government plans RE penetration of 100 % in its electrification system by 2030 (Ministry of Energy and Mining, 2013). This is also an ambitious target for the Kenyan Government to supply its power sector by 100 % of RE by 2030 (Climate Analytics, 2023). Therefore, no new fossil fuel-based power plant was expected in future and the existing ones will remain until the year 2030. This policy considers that the power sectors of the countries will be full decarbonized as from 2031 and all the fossil fuels power plants will be phased out after that year.

3.5.6 Demand Side Management

In this scenario, two policies, Efficient Lighting (EL) + Efficient Cooking Stoves (EFCS), were combined as there is a high probability that they are implemented at the same time.

3.6 Energy Model Validation Analysis

The reference scenario was used to validate the developed LEAP model for these countries. Therefore, real date between the years 2015 and 2020 were used. These data helped to determine the errors between them with the simulated results. Some other researchers also relied on this method to validate their modelling results (Alam et al., 1999; Gota et al., 2011).

In this study, each contribution in total error for energy consumption (error from each energy fuel consumed) and supply (error from each process in energy transformation) was computed.

CHAPTER FOUR

RESULTS AND DICUSSIONS

4.1 Multi-Criteria Decision Making Model

4.1.1 Weights of Criteria and Sub-criteria

The weights for the different criteria and sub-criteria were determined as follow: after experts' feedback was obtained, pairwise comparison matrices amongst criteria and sub-criteria were constructed. By applying AHP method, normalized weights for the different criteria and sub-criteria were obtained by using Eq. 3.1. The consistency ratios for each constructed pairwise comparison matrix were calculated using Eq. 3.2 and Eq. 3.3 and checked if their values are lower than 10 %.

Figure 4.1 shows the obtained weights of criteria for both countries while Figure 4.2 and Figure 4.3 for sub-criteria for Kenya and Burundi, respectively.

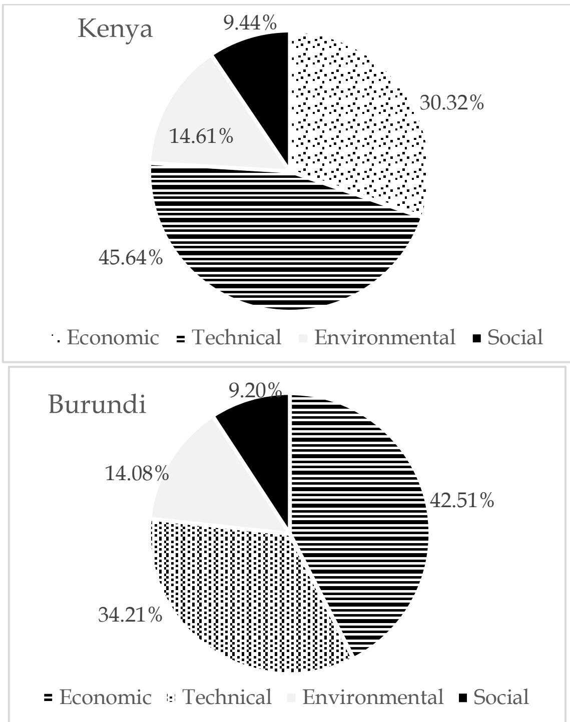


Figure 4.1: Normalized weights of criteria for Kenya and Burundi

From the results, the technical and economic criteria were with the highest weights in comparison to other criteria with the weights of 45.64 % and 30.32 % respectively, for

Kenya; and 34.21 % and 42.51 % respectively, for Burundi. Environmental and social dimensions were found with the weights of 14.61 % and 9.44 % respectively, for Kenya and 14.08 % and 9.20 % respectively, for Burundi. This was due to the fact that respondents gave a higher preference for resources availability, technology reliability and capacity factor for Kenya while higher preference was given to Capital costs and O & M costs for the case of Burundi. The economic criteria made of required capital and O & M costs was weighted the highest for Burundi and the second for Kenya; this may be explained by the fact that securing investments is an obstacle as access to capital is one of the major barriers to implementation of energy projects in African countries (Muzenda, 2009). Hence, technical and economic aspects were most preferred by respondents as compared to the other sustainable dimensions (social and environmental). The environmental criteria, with the weight of 14.61 % and 14.08 % came in the third position before the social criteria with 9.44 % and 9.20 % of weight for Kenya and Burundi, respectively.

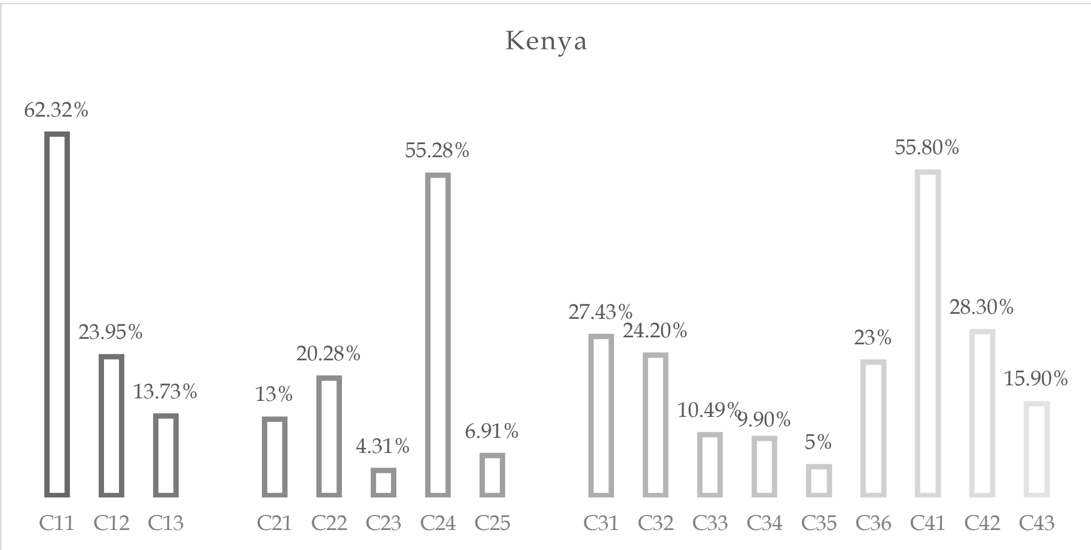


Figure 4.2: Normalized Weights of Sub-criteria for Kenya

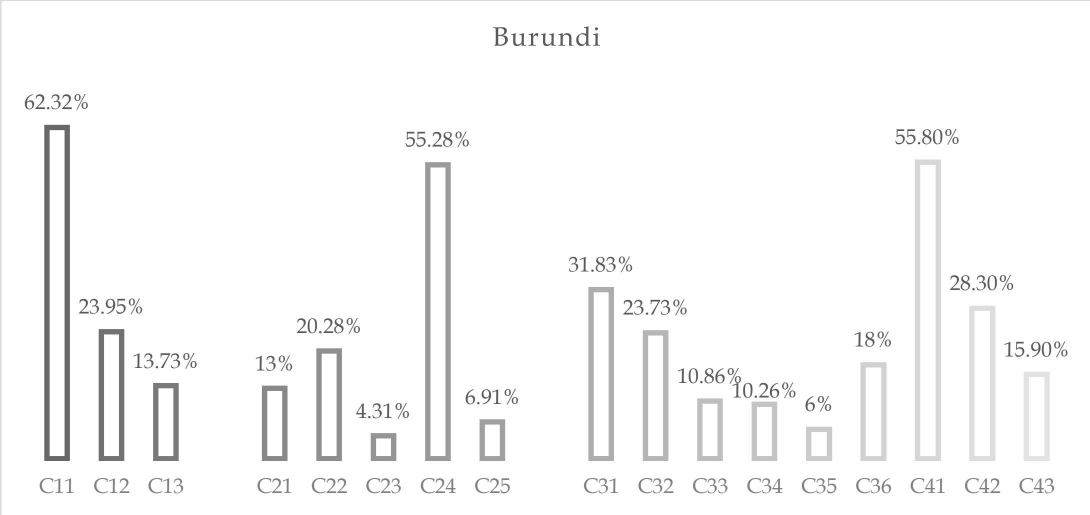


Figure 4.3: Normalized Weights of Sub-criteria for Burundi

4.1.2 Evaluation of Alternatives

The overall weights of each sub-criteria with regard to criteria were thereafter calculated after the determination of the weights for the different criteria and sub-criteria (Table 4.1 for Kenya and Table 4.2 for Burundi).

Table 4.1: Matrix of Sustainable Indicators Values for Kenya

Kenya	c_{11}	c_{12}	c_{13}	c_{21}	c_{22}	c_{23}	c_{24}	c_{25}	c_{31}	c_{32}	c_{33}	c_{34}	c_{35}	c_{36}	c_{41}	c_{42}	c_{43}
Hydro	1975	40	2	4	52.5	5	25	2	750	11	0.032	0.0155	0	67.5	0.27	0.945	68
PV	900	11.5	0	2	27.5	4	23000	−1	35	49.174	0.178	0.257	0	1	0.87	0.000245	94
CSP	7545	77.5	0	2	53.5	3	15400	1	40	16	0.068	0.042	0	3.02	0.23	0.000245	94
Wind	1250	33.25	0	4	46.5	5	1800	−1	100	22	0.065	0.055	0	0	0.17	0.00189	69
Geother	5275	13.5	16.5	5	85	4	87.6	1	18	18.913	0.28	0.02	0	156	0.25	0.00174	56
Biomass	2850	50	10	4	82.5	4	3.61	0	5000	69.25	0.89	0.485	40	134.25	0.21	0.0149	56
Oil	975	16.5	3.875	4	52.5	5	65.09	2	2.5	715	1	4.425	8	78	0.11	1.69	30
Coal	650	10	10	4	73	3	162.82	0	2.5	855	2.1	3.365	5.5	78	0.11	1.08	32

Table 4.2: Matrix of Sustainable Indicators Values for Burundi

Burundi	c_{11}	c_{12}	c_{13}	c_{21}	c_{22}	c_{23}	c_{24}	c_{25}	c_{31}	c_{32}	c_{33}	c_{34}	c_{35}	c_{36}	c_{41}	c_{42}	c_{43}
Hydro	1975	40	2	4	52.5	5	5	2	750	11	0.032	0.0155	0	67.5	0.27	0.945	68
PV	900	11.5	0	2	27.5	4	888	−1	35	49.174	0.178	0.257	0	1	0.87	0.000245	94
CSP	7545	77.5	0	2	53.5	3	786	1	40	16	0.068	0.042	0	3.02	0.23	0.000245	94
Wind	1250	33.25	0	4	46.5	5	12.1	−1	100	22	0.065	0.055	0	0	0.17	0.00189	69
Geother	5275	13.5	16.5	5	85	4	0.158	1	18	18.913	0.28	0.02	0	156	0.25	0.00174	56
Biomass	2850	50	10	4	82.5	4	5.96E-11	0	5000	69.25	0.89	0.485	40	134.25	0.21	0.0149	56
Peat	2010	23	4	4	91	2	0.055	0	2.5	1120	0.576	0.273	4.5	78	0.11	1.08	32

Matrix of sustainable indicators values was constructed by taking the values (or average) of sustainable indicators "sub-criteria" presented in Table 3.2, Table 3.3, Table

3.4 and Table 3.5 where the matrix elements are the indicators for the different power technology options in Kenya and Burundi. Therefore, the TOPSIS method was applied to the matrix made by the 17 sustainable indicators "sub-criteria" for the 8 alternatives for Kenya and 7 alternatives for Burundi as shown by Figure 4.4 for Kenya and Figure 4.5 for Burundi, following the steps of Eq. 3.4 to Eq. 3.10.

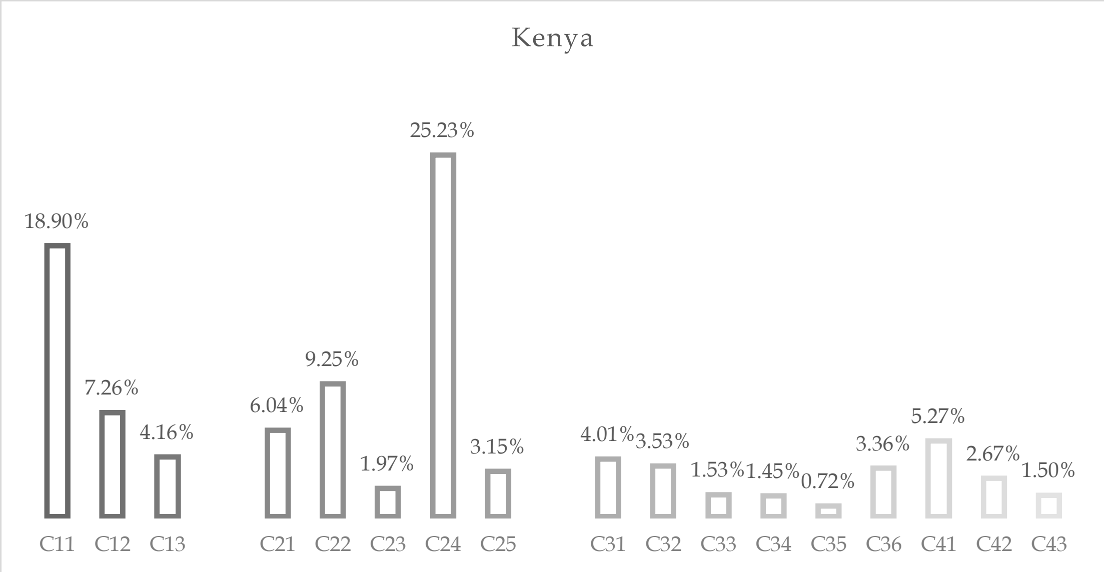


Figure 4.4: Sub-criteria Overall Weights with Regard to Criteria for Kenya

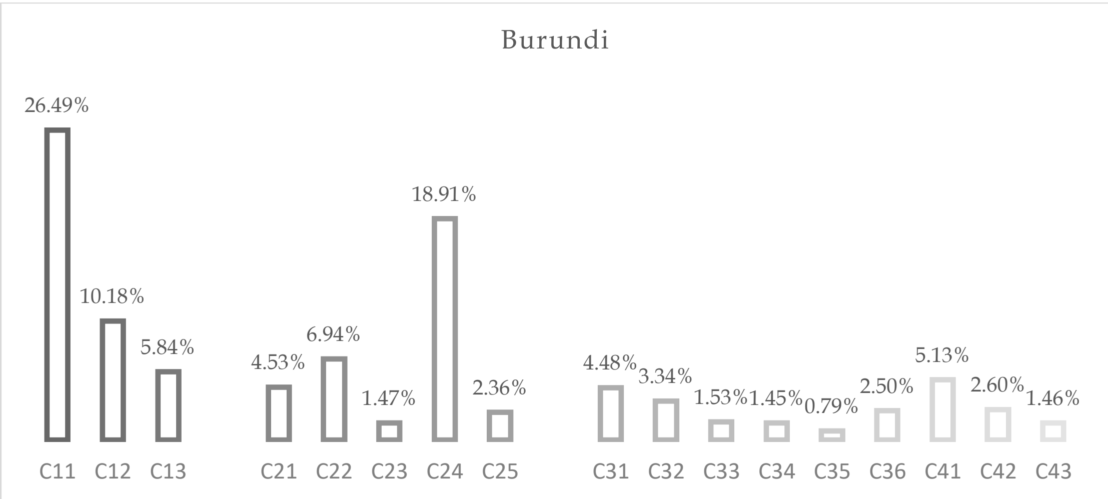


Figure 4.5: Sub-criteria Overall Weights with Regard to Criteria for Burundi

The Relativeness Closeness to Ideal Solution Ci* was then determined (Figure 4.6). This helped to rank the different technologies (Table 4.3).

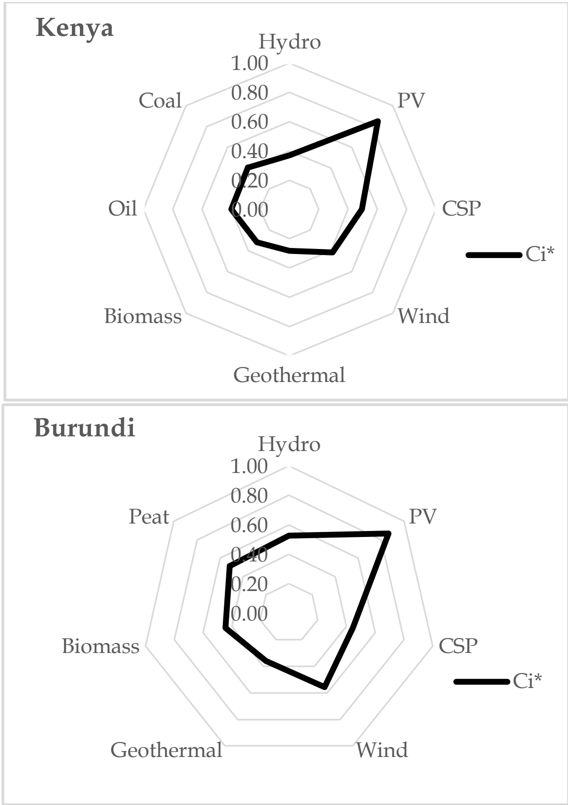


Figure 4.6: Determined Relativeness Closeness to Ideal Solution for Kenya and Burundi

With regards to respondents' criteria weights, RE (Solar PV, Wind and CSP for Kenya and Solar PV, Wind and Hydro for Burundi) occupied the first positions. The most sustainable power technology was solar PV with a higher priority. This technology has the highest resource potential in the both countries and it has the lowest capital and O&M costs compared to other technologies.

Table 4.3: Technologies Prioritization Based on Respondents' Criteria weights

Kenya		Burundi	
Alternative	Rank	Alternative	Rank
Hydro	6	Hydro	3
PV	1	PV	1
CSP	2	CSP	5
Wind	3	Wind	2
Geothermal	8	Geothermal	7
Biomass	7	Biomass	6
Oil	5	Peat	4
Coal	4	-	-

4.1.3 Scenarios Analysis

Although the results obtained (as presented in Table 4.3) show a higher policy preference for solar PV, CSP and Wind for Kenya and Solar PV, Wind and Hydro for Burundi in first positions respectively, there may raise arguments concerning this outcome due to input values in the analysis. Therefore, input data (likely to vary) were analyzed by performing a scenarios analysis.

This is in agreement with Schnaars: scenarios analysis is a prevalent method of looking at future business environment (Schnaars, 1987). This is an important technique which can be used in trying to identify possible future situations (Schnaars, 1987). In energy sector, various developed scenarios provide an important support to decision makers and the results are dependent on input data derived from assumptions (Weimer-Jehle et al., 2016). In that regard, this study sought to find a most (or least) promising technology in case one or the other sustainable dimension may be given more importance by decision makers than another. Therefore, scenarios were performed by varying the weights of the sustainable dimensions. Some assumptions regarding the weightage of the main criteria were considered. The analysis was performed by assuming that a privileged criterion is subject to being given a weight which is double of the others' whereas equal weight was considered by assuming equal importance for all the criteria. Hence, five distinct scenarios cases were analyzed: economic criteria most privileged, technical criteria most privileged, environmental criteria most privileged, social criteria most privileged and criteria given the same importance. The different analyzed scenarios are illustrated on Figure 4.7 for Kenya and Figure 4.8 for Burundi.

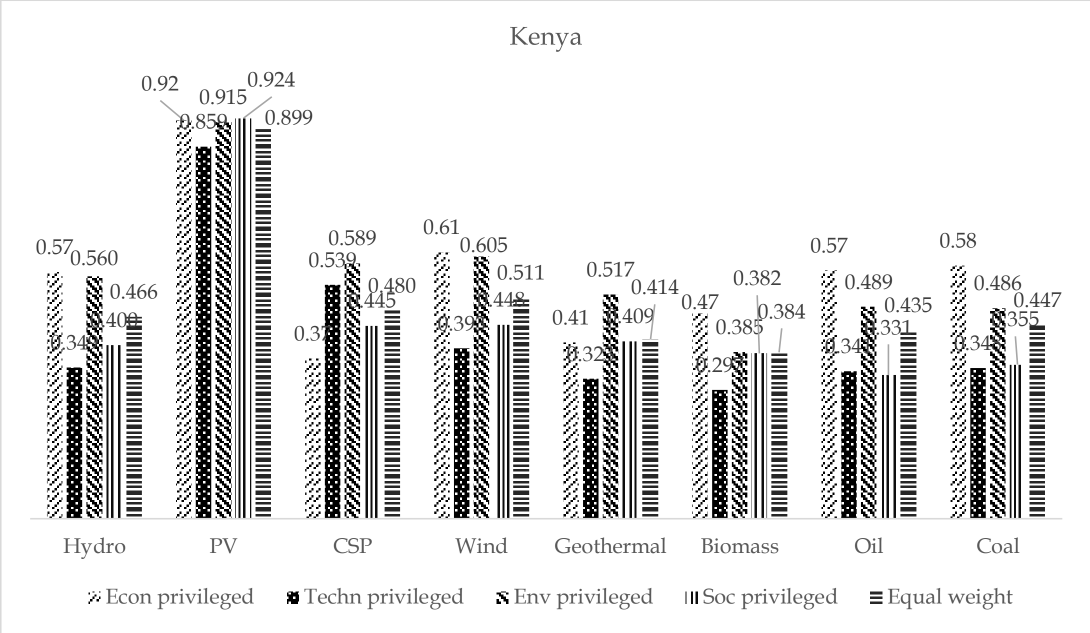


Figure 4.7: Kenyan Scenarios Analysis with Regard to Criteria

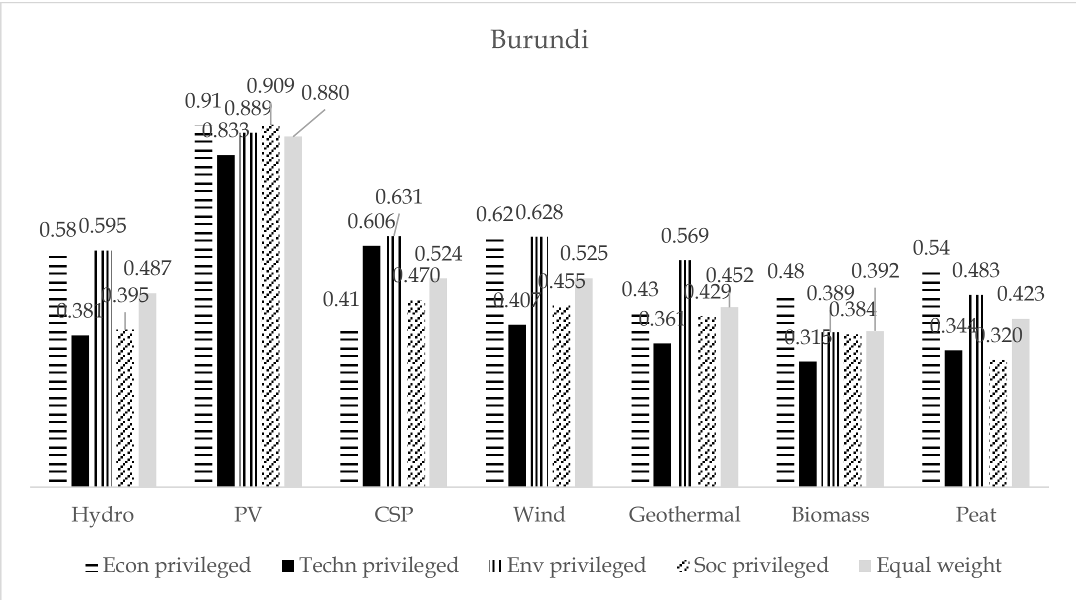


Figure 4.8: Burundian Scenarios Analysis with Regard to Criteria

Scenario 1: Technologies Weighted for Economic scenario

In this scenario, economic criterion was considered as the most privileged dimension compared to others. A weight of 40 % was given to this indicator while the three other criteria shared the 60 %. Here, minimal Capital and O&M costs were considered as most important indicators to be privileged. This scenario is illustrated on Figure 4.7 for Kenya and Figure 4.8 for Burundi.

In this scenario, Solar PV, Wind and Coal were respectively the most economic technologies in Kenya while CSP was the least. For the case of Burundi, Solar PV, Wind and Hydropower were respectively the most economic technologies while CSP was the least.

Scenario 2: Technologies Weighted for Technical scenario

In this scenario, technical criterion was considered as the most important compared to other dimensions and was given a weight of 40 % while others shared the remaining 60 %. Here, an emphasis was given to maximal capacity factor, reliability, technology maturity, ability to respond to peak load and resources availability.

In this scenario, Solar PV, CSP and Wind were respectively the most technically suitable technologies in both countries while Biomass was the least as illustrated on Figure 4.7 for Kenya and Figure 4.8 for Burundi.

Scenario 3: Technologies Weighted for Environmental Scenario

In this scenario, the environmental dimension was privileged with respect to other dimensions and was given a weight of 40 % while others shared the remaining 60 %. Here, an emphasis was given to a technology with minimal land requirement and least pollution emissions and water consumption.

In this scenario, Solar PV, Wind, CSP were respectively the most environmentally friendly technologies in Kenya while they were respectively Solar PV, CSP and Wind for Burundi. The Biomass was the least in both countries as illustrated on Figure 4.7 for Kenya and Figure 4.8 for Burundi.

Scenario 4: Technologies Weighted for Social scenario

In this scenario, the importance was given to a technology with a high job creation potential and social acceptability. The social criterion was then considered as the most important compared to other dimensions and was given a weight of 40 % while others shared the remaining 60 %.

In this scenario, Solar PV, Wind and CSP were respectively the most social technologies in Kenya while they were respectively Solar PV, CSP and Wind for Burundi as illustrated on Figure 4.7 for Kenya and Figure 4.8 for Burundi.

Scenario 5: Equal Weighted Technologies Scenario

This scenario, all dimensions were equally treated and each criterion was then given a weight of 25 %. This scenario is illustrated on Figure 4.7 for Kenya and Figure 4.8 for Burundi.

If the sustainable dimensions were equally treated, Solar PV, Wind and CSP were respectively the most promising technologies in the both countries while Biomass was the least.

It was clear that RE (especially Solar PV, Wind and CSP), Biomass excluded, always occupied first positions in most all scenarios. Solar PV technology was found the most sustainable technology in the countries compared to other technologies. With a massive exploitation of fossil fuels considered in this study (available reserves were considered to be totally exploited in the next 20 years), they were not found to compete with RE (especially Solar PV, Wind and CSP) in all the scenarios, except in economic scenario where CSP occupied the last position.

Therefore, the high deployment of RE technologies in the countries would not harm their economic growth. The results obtained in this study come to reinforce government strategies of these countries for their energy mix policy (Ministry of Energy, 2018).

4.2 Analysis of Current and Future Energy Demand and Supply

4.2.1 Trend Analysis of Energy Intensity

The energy intensities of different fuels used in residential sector of the countries were gathered from different sources in the methodology section. In this section, results of energy intensities in economic sectors are determined.

The energy intensities in economic sectors of the countries were established based on the historical energy consumptions per sector and GDP shares of the different economic sectors, historical energy intensity levels (TJ/USD) for the various sectors. There is a declining trend of energy intensity levels for many different fuels used in the different sectors, especially for Kenyan case.

4.2.1.1 Agricultural Sector

In Kenyan agricultural sector, the historical trend shows that energy intensity of oil products is dropping based on historical data (2000 – 2015) as shown by Figure 4.9. This was 9.4508E-07 TJ/USD (0.263 kWh/USD) in 2000 and became 4.75373E-08 TJ/USD (0.0132 kWh/USD) in 2015 for oil products. In this sector, the reference scenario expects intensity for oil products to decline up to 3.66616E-08 TJ/USD (0.010183778 kWh/USD) by 2020 and to 5.07494E-10 TJ/USD (0.000140971 kWh/USD) by 2040 based on the historical trend. Dissimilarly to the Kenyan case, the historical trend for Burundi agricultural sector shows a rising trend in energy intensity of oil products and wood (Figure 4.9). This was 3.67544E-09 TJ/USD in 2006 and became 4.58785E-09 TJ/USD in 2016 for oil products while it was 1.97954E-07

TJ/USD for wood in 2008 before rising to 3.80252E-07 TJ/USD in 2016. Therefore, the reference scenario expects intensity for oil products to slightly rise up to (0.005888894 kWh/USD) by 2020 and to 0.006222227 kWh/USD by 2040 based on the historical trend. For wood, intensity is expected to be 1.62554E-06 TJ/USD (0.451540525 kWh/USD) by 2040.

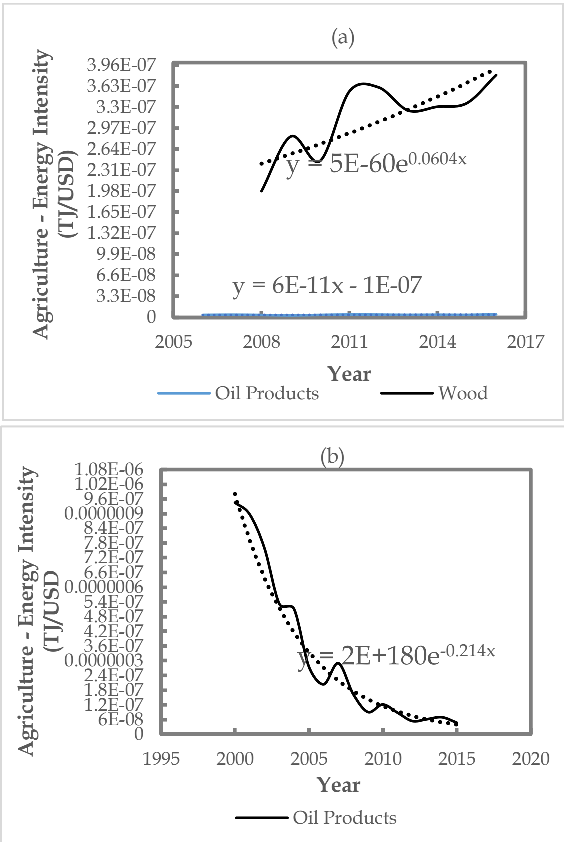


Figure 4.9: Historical Trends of Agricultural Energy Intensity for (a) Burundi and (b) Kenya

4.2.1.2 Industrial Sector

In Industrial sector, the historical trend of energy intensity for all fuels is declining for Kenya (Figure 4.10) : it was 2.26016E-06 TJ/USD (0.628 kWh/USD), 1.65983E-06 TJ/USD (0.461 kWh/USD) and 1.25002E-06 TJ/USD (0.347 kWh/USD) for oil products, coal and electricity respectively in 2015 and is expected to become 7.24574E-08 TJ/USD (0.020127056 kWh/USD), 6.96039E-07 TJ/USD (0.193344167 kWh/USD) and 2.17012E-07 TJ/USD (0.060281111 kWh/USD) in 2040 for oil products, coal and electricity respectively, in reference scenario.

For Burundi, only oil products are expected with a decreasing energy intensity in reference scenario (Figure 4.10). The intensity was 1.44229E-08 TJ/USD (0.004 kWh/USD), 9.60776E-08 TJ/USD (0.0267 kWh/USD) and 1.44084E-07 TJ/USD (0.04 kWh/USD) for oil products, wood and electricity respectively in 2015 and is expected to become 2.24E-08 TJ/USD (0.006222227 kWh/USD), 0.0000012 TJ/USD (0.3333336 kWh/USD) and 4.36548E-08 TJ/USD (0.012126347 kWh/USD) in 2040 for oil products, wood and electricity respectively in reference scenario.

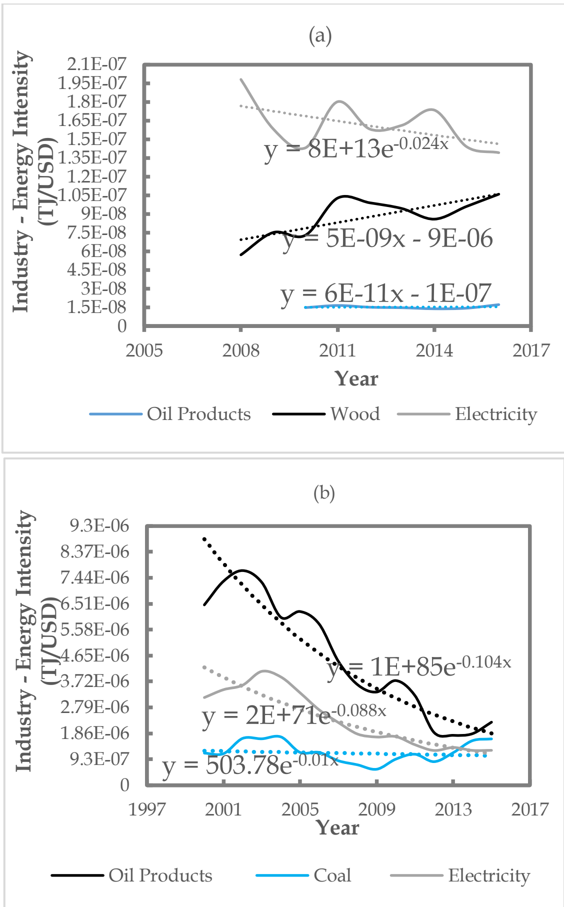


Figure 4.10: Historical Trends of Industrial Energy Intensity for (a) Burundi and (b) Kenya

4.2.1.3 Transport Sector

The historical energy intensity trend in transport sector is decreasing for the both countries (Figure 4.11). In 2040, energy intensity in transport sector is expected to decline to 2.26181E-06 TJ/USD (0.62828087 kWh/USD) for oil products in Burundi whereas it is expected to drop up to 3.69555E-06 TJ/USD (1.026541658 kWh/USD) for Kenya.

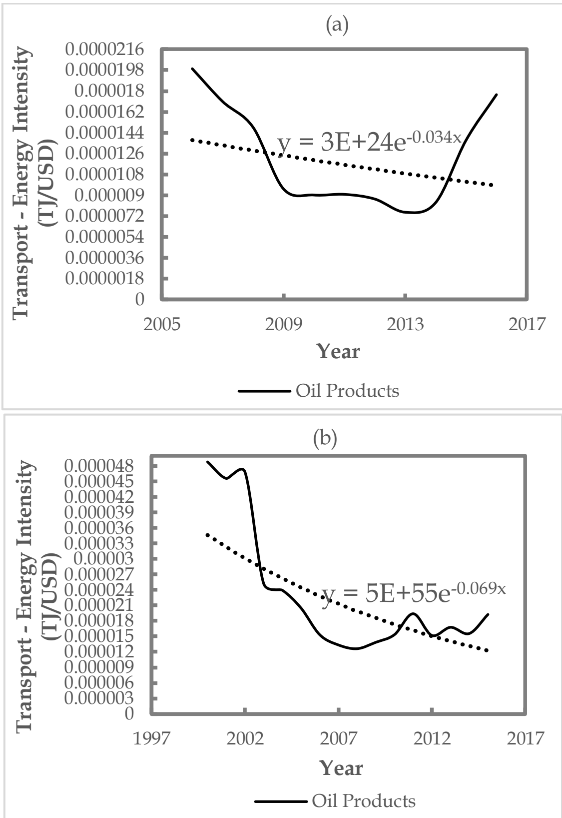


Figure 4.11: Historical Trends of Transport Energy Intensity for (a) Burundi and (b) Kenya

4.2.1.4 Sector of Commercial, Service and Other

Based on the historical trends (Figure 4.12), the reference scenario for Commercial, Service and Other expects energy intensity for oil products to become 4.54736E-09 TJ/USD (0.001263157 kWh/USD) and 2.13097E-09 TJ/USD (0.000591936 kWh/USD) for oil products and electricity respectively by 2040 for Kenya while it is expected to become 0.00000022 TJ/USD (0.06111116 kWh/USD), 8.58526E-09

TJ/USD (0.002384797 kWh/USD), 1.13698E-06 TJ/USD (0.315826741 kWh/USD) and 1.47984E-09 TJ/USD (0.000411066 kWh/USD) for oil products, electricity, wood and peat, respectively, by 2040 for Burundi.

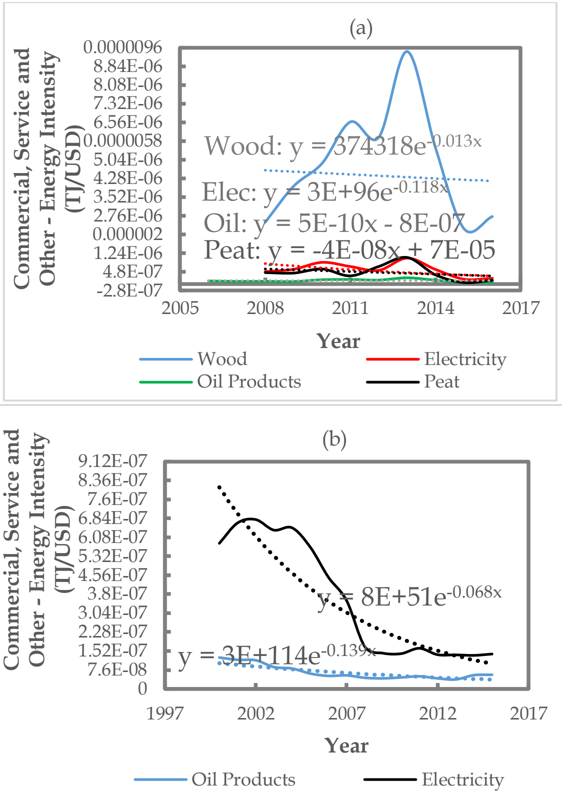


Figure 4.12: Historical Trends of Intensity in Commercial, Service and Other for (a) Burundi and (b) Kenya

4.2.2 Current and Future Energy Demand: Reference Scenario

The current and future energy demand was built as baseline scenario where historical trends of population, economic characteristics, rate of electrification and urbanization, and energy consumption (energy intensity) were used as key input data to perform this demand. Energy demand will keep rising in both countries. This was 178,993.9 TJ in 2015 and is projected to grow up to 417,980.0 TJ in 2040 for Burundi while it was 685,331.5 TJ in 2015 and is expected to grow up to 857,518.3 TJ in 2040 for Kenya. Table 4.4 and Table 4.5 shows projected energy demand by sector in Kenya and Burundi, respectively.

Table 4.4: Total Energy Demand (TJ) by Sector for Kenya

Year	Households	Industry	Transport	Agriculture	Com. S&O	**Total**
2015	500,378.6	64529.1	113388.8	1000.0	6035.0	**685,331.5**
2020	533,327.7	44085.0	132296.8	912.6	2267.9	**712,890.0**
2025	563,054.7	43118.0	129965.9	426.7	1702.4	**738,267.7**
2030	599,272.5	43980.6	127516.1	199.4	1317.2	**772,285.9**
2035	638,392.5	46824.4	124968.2	93.2	1051.2	**811,329.5**
2040	682,369.5	51902.6	122338.4	43.5	864.2	**857,518.3**

Note: Com. S & O: Commercial, Service and Others

Table 4.5: Total Energy Demand (TJ) by Sector for Burundi

Year	Households	Industry	Transport	Agriculture	Com. S & O	**Total**
2015	170,704.2	161.2	4781.2	323.8	2963.4	**178,933.9**
2020	181,877.2	1525.7	5228.2	910.9	4154.4	**193,696.4**
2025	192,753.7	3142.5	12751.2	2268.9	7267.4	**218,183.8**
2030	203,477.3	6467.7	28773.8	5572.2	12850.8	**257,141.8**
2035	213,808.5	13298.3	61935.6	13413.1	3709.1	**306,164.6**
2040	223,439.0	27310.4	129150.3	31366.0	6714.4	**417,980.0**

Note: Com. S & O: Commercial, Service and Others

Despite the decrease in total energy share for the Burundian residential sector by 2040 (Figure 4.13), the energy demand by this sector is projected to rapidly increase in Burundi as well as in Kenya. For Kenya, the total energy demand by households was 500,378.6 TJ in 2015 and is projected to increase up to 682,369.5 TJ in 2040. The increase is also expected for Burundi as the demand for households was 170,704.2 TJ in 2015 and is projected to become 223,439.0 TJ in 2040. Between the years 2015 and 2040, the total energy demanded by households is characterized by a slow growth in these countries with 1.36 times for Kenya and only 1.31 times for Burundi. This is may be justified by energy demand by households in saturation mode and the marginal increase is initiated by the population growth causing an increase in number of households. However, households will remain the main consumer of final energy in the both countries as their consumption is expected to constitute 79.6 % and 53.5 % of total energy demand by 2040 for Kenya and Burundi, respectively as shown by Figure 4.13 (for Kenya) and Figure 4.14 (for Burundi); despite the remarkable decrease of share for Burundi which was 95.4 % in 2015. This largest final energy share for households' consumption was also noticed in some other sub-Saharan Africa like Nigeria (Adamu et al., 2020).

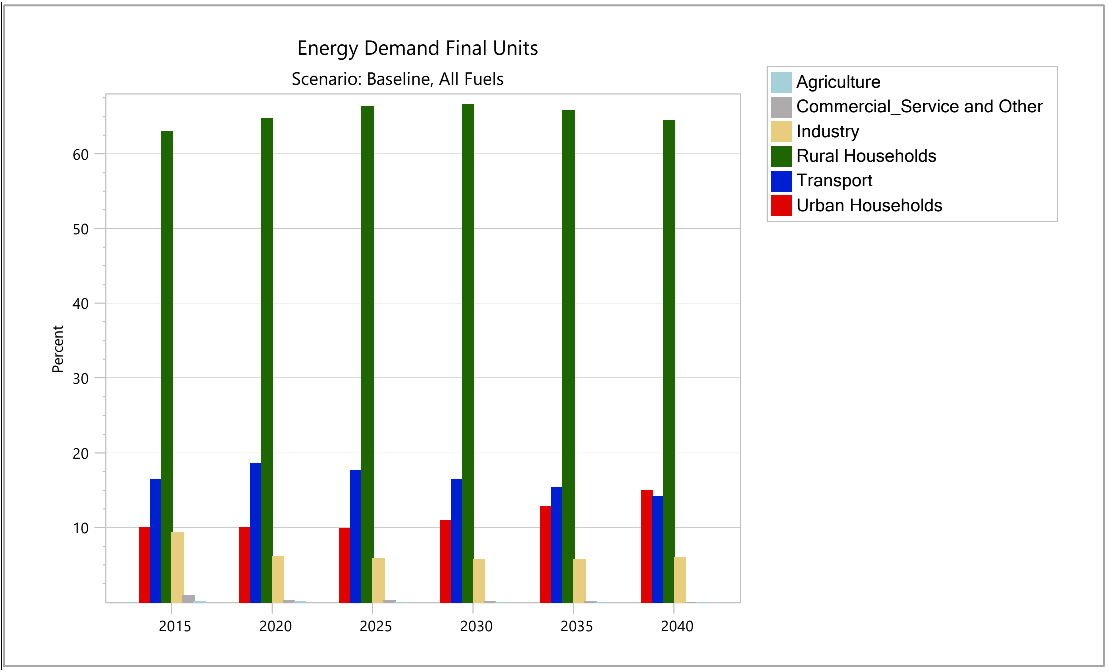


Figure 4.13: Percentage Share of Kenyan Total Energy Demand per Sector

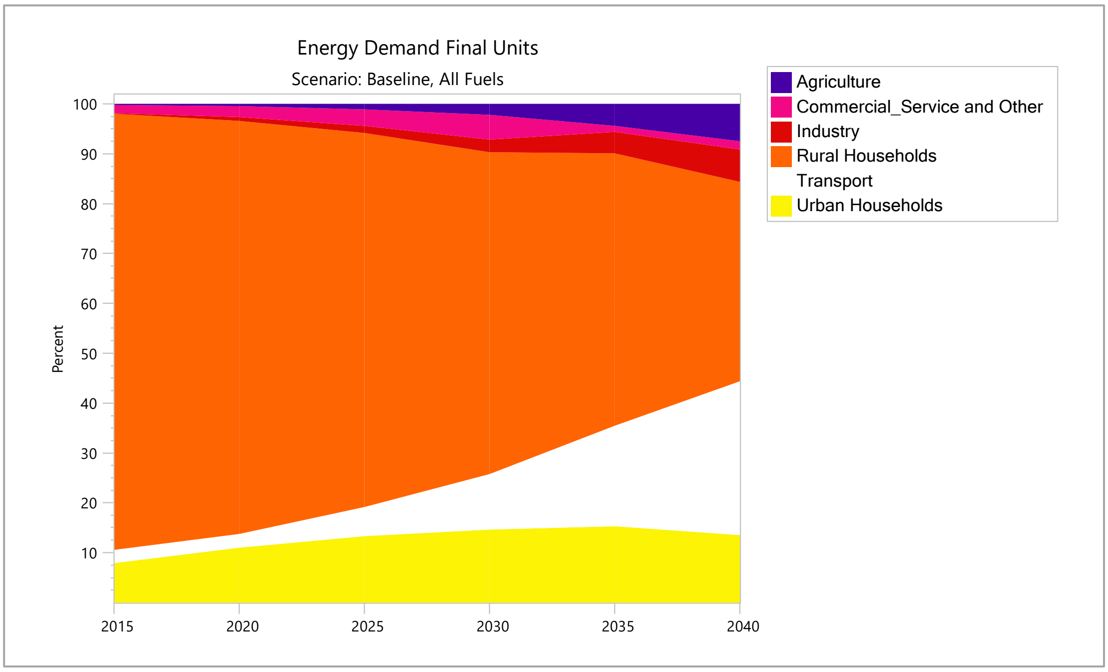


Figure 4.14: Percentage Share of Burundian Total Energy Demand per Sector

For Kenya, the share for the residential sector was 73.0 % in 2015 and it is expected to slightly rise up to 79.6 % in 2040. This may be justified by the decreasing trends of energy intensities for most all the fuels used in the Kenyan economic sectors while it is not the case for Burundi. This can be demonstrated by the yearly percent growth of total energy demand for Kenya (Figure 4.15) and Burundi (Figure 4.16).

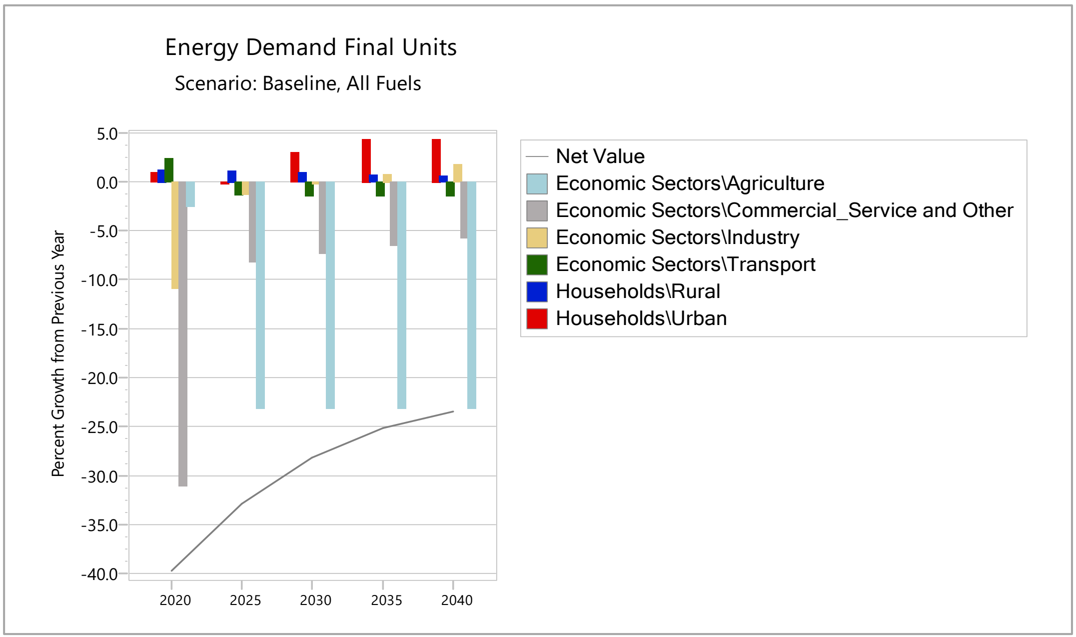


Figure 4.15: Total Energy Demand Growth rate per Sector (Kenya)

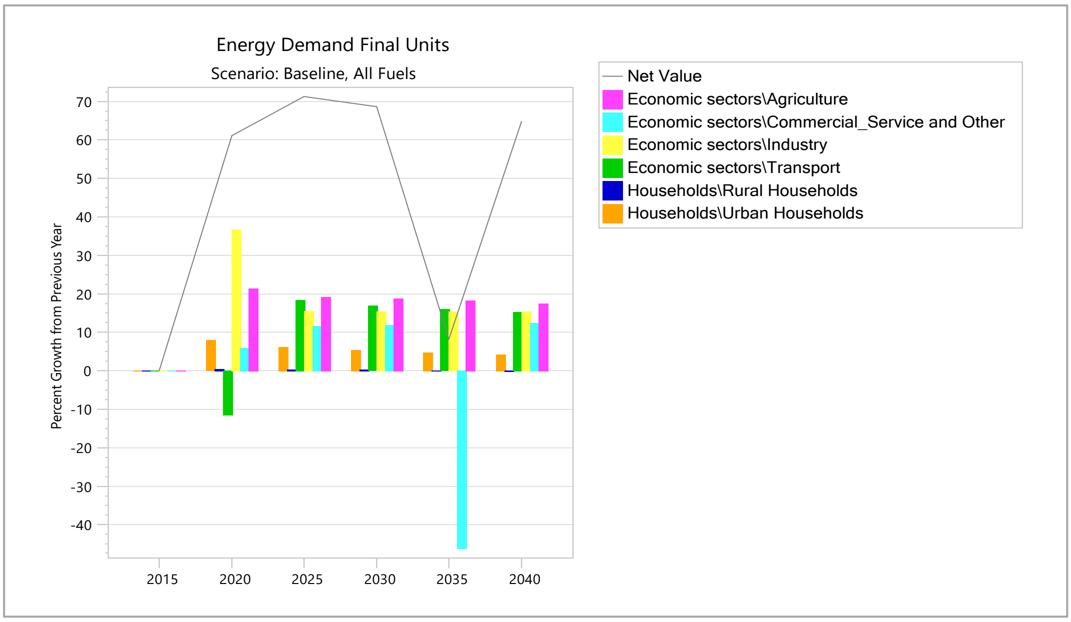


Figure 4.16: Total Energy Demand Growth rate per Sector (Burundi)

In the residential sector, the results show that energy demand by rural households will continue to grow as compared to urban households. Table 4.6 and Table 4.7 show results of projected energy demand for urban and rural households in both countries as per fuel consumption.

Table 4.6: Total Energy Demand (TJ) by Urban and Rural Households for Burundi

Year	Urban Households							Rural Households						
	Electricity	Kerosene	Peat	Firewood	Charcoal	Solar	Other	Electricity	Kerosene	Peat	Firewood	Charcoal	Solar	Other
2015	166.4	117.0	34.3	3,960.9	9,802.0	0.7	100.3	174.4	1,262.3	62.3	49,177.8	4,878.4	5.7	961.7
2020	307.6	141.0	186.5	4,976.5	15,718.1	1.1	105.9	226.1	1,339.0	150.6	149,689.5	7,719.3	10.0	1,306.1
2025	504.2	147.3	459.7	5,475.5	22,399.5	1.5	132.8	271.7	1,493.9	250.7	149,035.5	10,61.6	14.8	1 ,704.9
2030	764.5	134.3	894.0	5,208.3	30,424.4	2.1	155.7	319.8	1,658.6	363.0	147,068.5	14,317.3	20.2	2,146.4
2035	1,097.2	89.8	1,539.0	3,858.5	39,987.0	2.2	171.7	369.8	1,831.8	487.4	143,644.4	18,073.6	26.2	2 ,629.7
2040	1,510.1	-	2,456.5	1,026.1	51,300.1	2.1	177.2	421.2	1,956.2	623.4	138,676.2	22,105.0	32.7	3,152.2

Other: Vegetal wastes

Table 4.7: Total Energy Demand (TJ) by Urban and Rural Households for Kenya

Year	Urban Households							Rural Households						
	Electricity	Kerosene	LPG	Firewood	Charcoal	Solar	Other	Electricity	Kerosene	LPG	Firewood	Charcoal	Solar	Other
2015	4,744.6	4,675.1	4,889.2	40,825.8	13,016.4	2.0	8.9	3,015.6	8,304.9	1,759.9	402,183.7	16,835.8	59.3	57.4
2020	6,531.2	4,070.7	7,615.2	42,360.4	10,952.3	1.4	383.8	5,063.8	7,191.1	2,969.8	424,270.1	21,590.4	52.5	275.0
2025	8,795.5	3,127.1	11,576.7	38,281.0	11,030.2	0.3	220.7	7,472.3	5,799.2	4,364.7	444,689.1	27,085.8	43.0	569.2
2030	10,879.1	1,397.6	16,003.9	45,694.7	10,141.3	-	558.9	10,226.0	4,016.8	5,835.0	460,260.1	33,152.7	30.3	1,076.2
2035	13,194.8	885.3	20,972.1	59,950.4	8,620.8	-	807.5	13,316.0	1,878.4	7,553.8	469,940.4	39,662.6	14.2	1,596.2
2040	15,896.5	-	27,323.1	78,159.9	6,551.8	-	1,143.6	16,131.0	-	9,293.6	479,621.0	46,119.7	-	2,129.3

Other: vegetal wastes

In the Kenyan residential sector, the most increase is expected to be originated from electrified rural area (Figure 4.17). This may be explained by the big number of households in rural area and the fact that the electrification is expected to rapidly increase in both urban and rural areas. Figure 4.17 shows the share of energy consumption by different sub-sectors in the Kenyan residential sector.

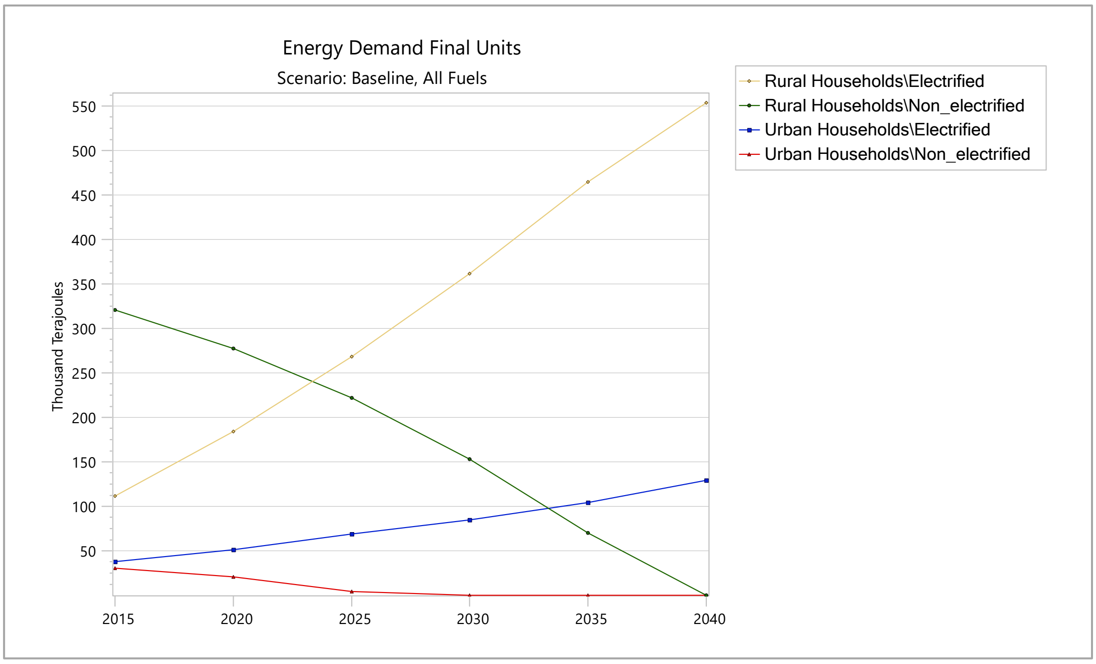
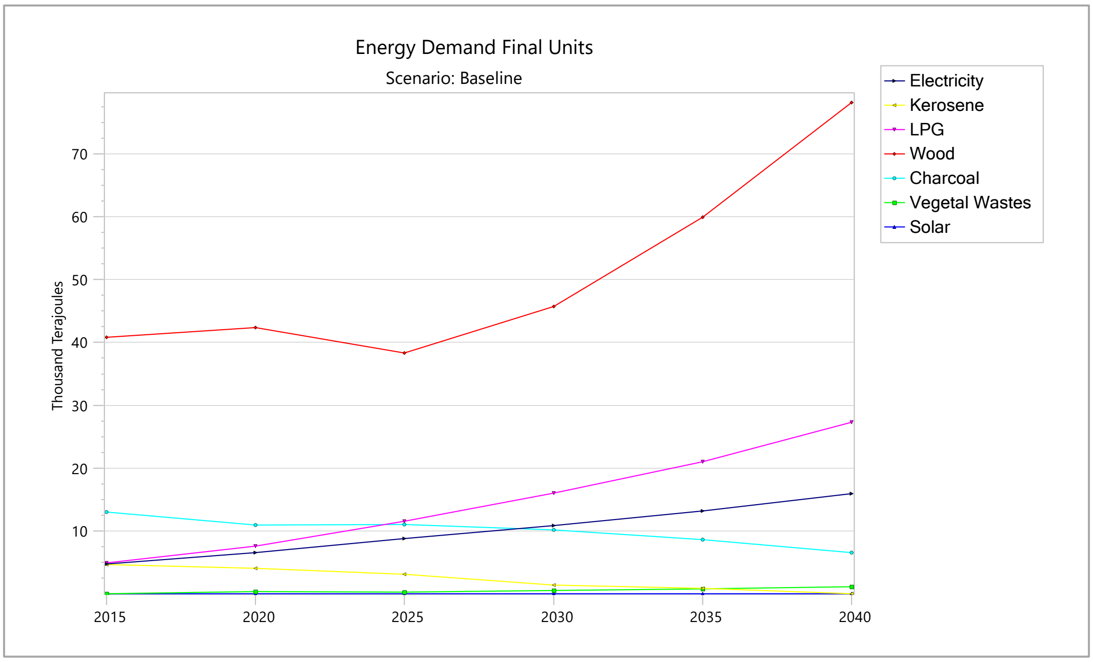


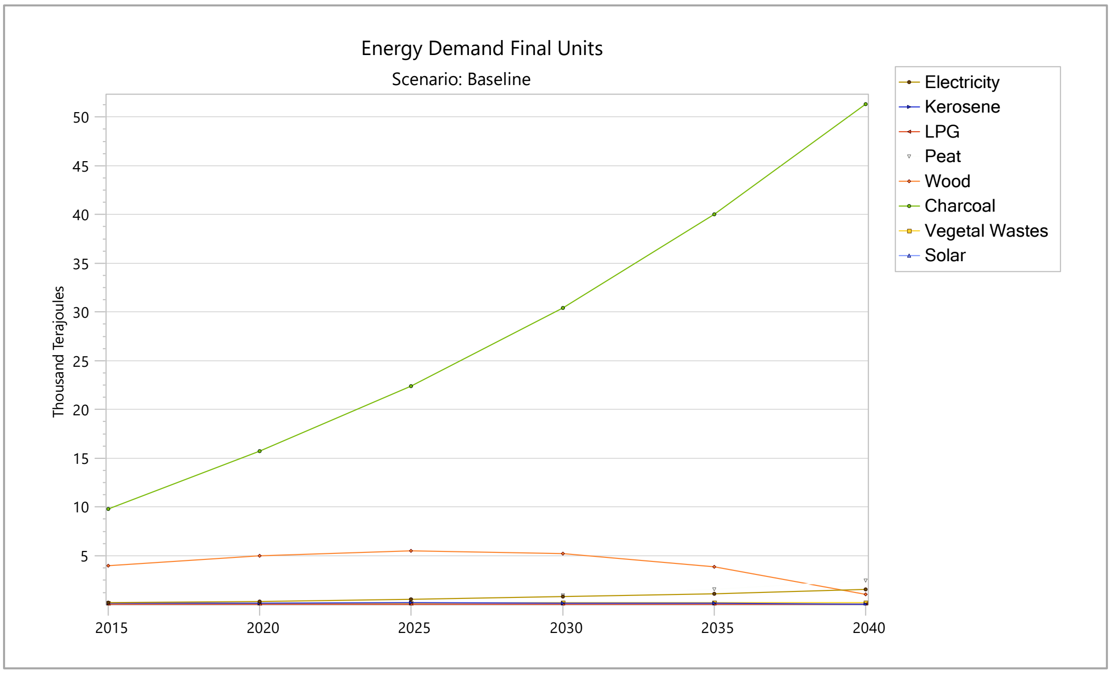
Figure 4.17: Trend of Total Energy Demand by Kenyan Residential Sector

The results show that firewood will remain the main fuel for rural households for the study period for Kenya and Burundi by 2040. The firewood will constitute 81.7 % in total energy demand by residential sector and 65 % in total final energy demand by all sectors for the case of Kenya. For the case of Burundi, the firewood will constitute 62.5 % in total energy demanded by the residential sector and 47 % in total final energy demanded by all sectors. Figure4.18 and Figure 4.20 show how the biomass will remain the main fuel consumed in Kenyan urban and rural areas, respectively whereas Figure4.19 and Figure 4.21 show how the biomass will remain the main fuel consumed in Burundian urban and rural respectively.



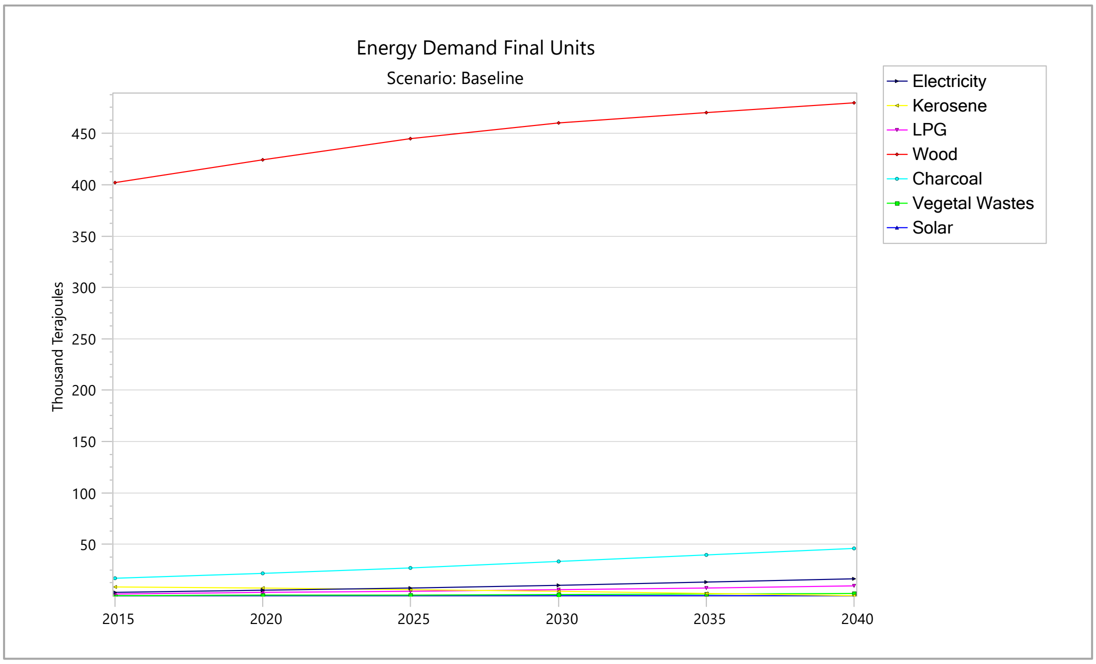
Note: Here wood refers to firewood

Figure 4.18: Trend of Total Energy Demand by Kenyan Urban Households



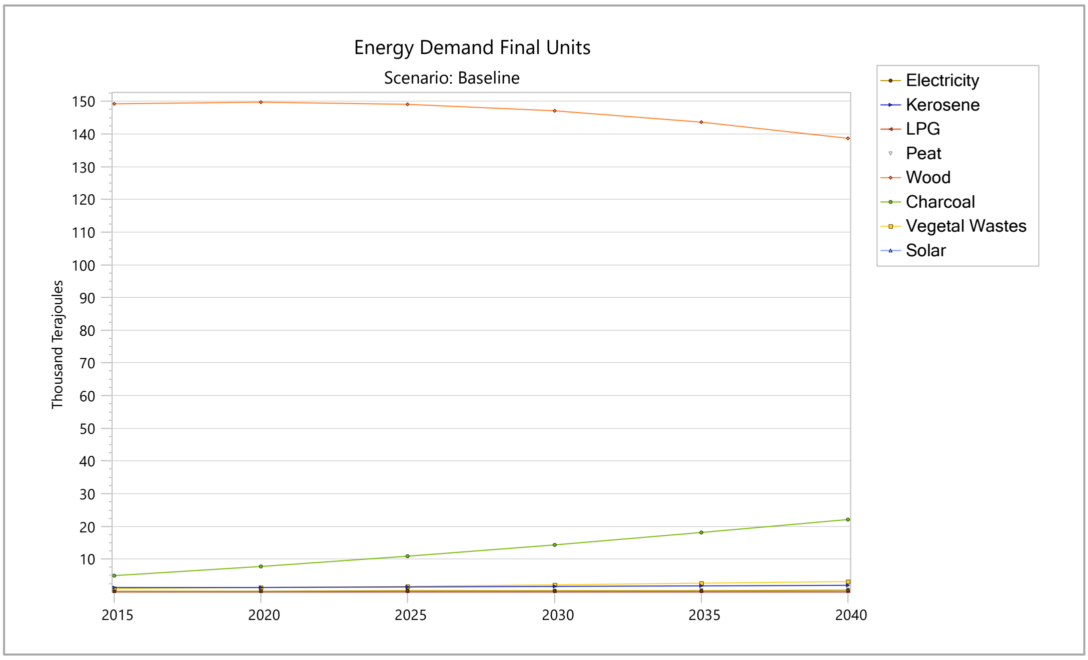
Note: Here wood refers to firewood

Figure 4.19: Trend of Total Energy Demand by Burundian Urban Households



Note: Here wood refers to firewood

Figure 4.20: Trend of Total Energy Demand by Kenyan Rural Households



Note: Here wood refers to firewood

Figure 4.21: Trend of Total Energy Demand by Burundian Rural Households

Some fuels are expected with a high demand while others are expected to have a declining trend. Table 4.8 and Table 4.9 show the per fuel total energy demand in the both countries. In Kenya the total demand is expected to be composed of electricity, LPG, oil, coal, firewood, charcoal and vegetal wastes by 2040. For the case of Burundi, the total demand is expected to be composed of electricity, kerosene, oil, peat, firewood, charcoal, vegetal wastes and solar by 2040.

Table 4.8: Per fuel Total Energy Demand (TJ) for Burundi

Year	Electricity	Kerosene	Oil*	Peat	Firewood	Charcoal	Vegetal Wastes	Solar	Total
2015	924.0	1,379.2	4,858.5	155.0	156,142.8	14,680.5	1,062.0	6.4	179,208.3
2020	1,249.7	1,480.0	5,762.8	467.4	160,295.2	23,437.5	1,411.9	11.1	194,115.6
2025	1,752.4	1,641.2	13,795.0	810.8	165,662.8	33,261.1	1,837.8	16.4	218,777.6
2030	2,412.4	1,792.9	30,794.7	1,333.6	174,545.0	44,741.7	2,302.1	22.4	257,944.8
2035	3,287.2	1,921.6	65,808.5	2,084.3	173,224.2	58,060.7	2,801.4	28.4	307,216.4
2040	4,469.4	1,956.2	136,480.4	3,123.1	196,527.5	73,405.1	3,329.4	34.8	419,325.9

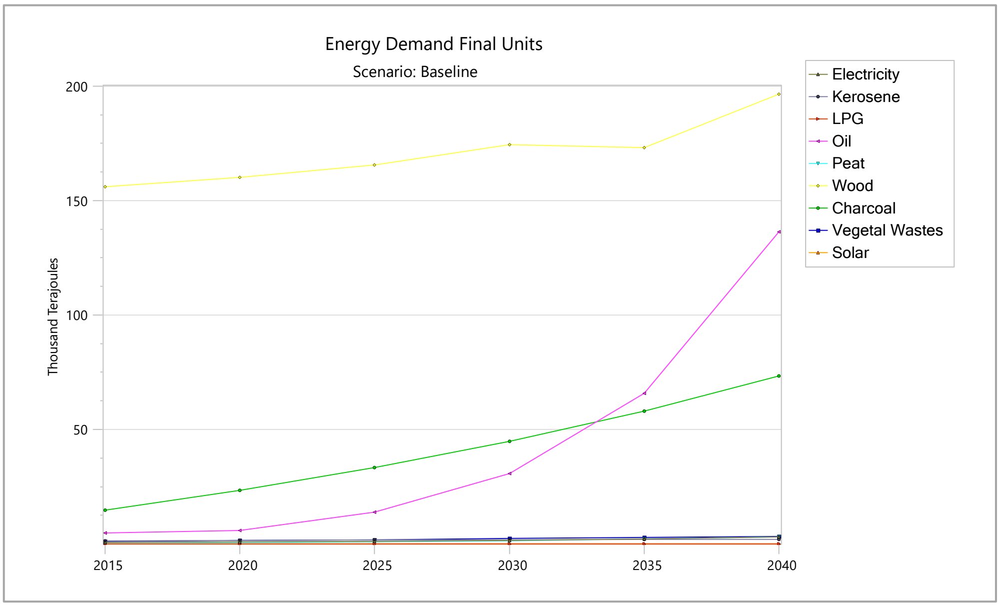
Oil*: Here, oil refers to "petroleum products" exclusively used in the economic sectors (Agriculture, Transport, Industry, Commercial, service and others).

Table 4.9: Per fuel Total Energy Demand (TJ) for Kenya

Year	Electricity	Kerosene	LPG	Oil*	Coal**	Firewood	Charcoal	Vegetal Wastes	Solar	Total
2015	27,657.2	12,980.0	6,649.1	144,338.9	20,717.1	443,009.4	29,852.2	66.3	61.4	685,331.5
2020	33,751.6	11,261.8	0,585.0	143,480.9	13,924.8	466,630.5	32,542.7	658.8	53.9	712,890.0
2025	35,066.6	8,926.3	5,941.3	138,677.0	17,737.1	482,970.0	38,116.1	789.8	43.3	738,267.7
2030	37,114.4	5,414.3	1,839.0	134,410.9	22,593.1	505,954.7	43,294.0	1,635.1	30.3	772,285.9
2035	40,184.3	2,763.6	8,526.0	130,484.8	28,778.6	529,890.8	48,283.4	2,403.7	14.2	811,329.5
2040	43,732.4	-	6,616.7	126,786.4	36,657.5	557,780.9	52,671.5	3,272.9	-	857,518.3

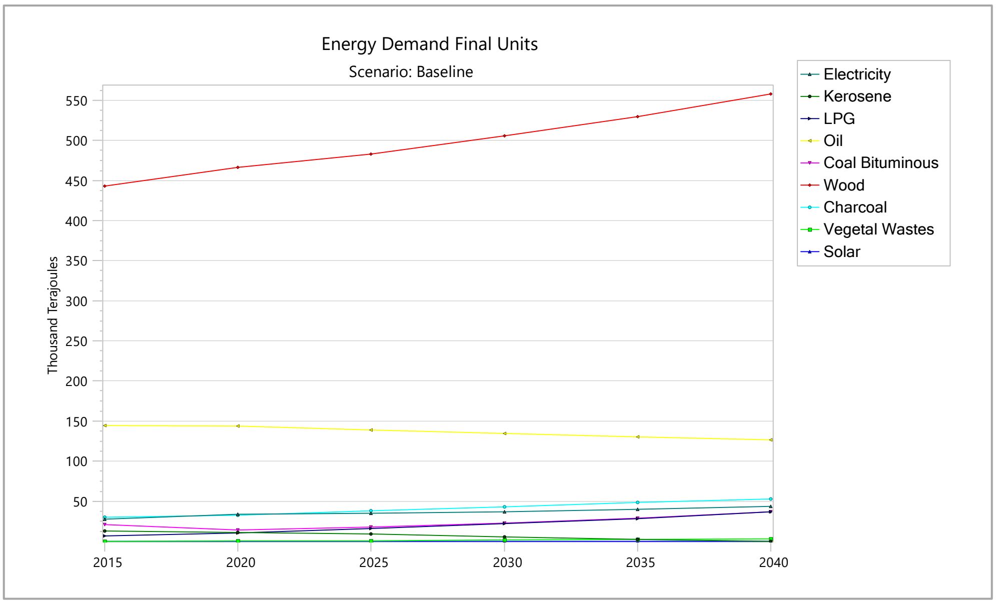
Coal**: Coal Bituminous; Oil*: Here, oil refers to "petroleum products" exclusively used in the economic sectors (Agriculture, Transport, Industry, Commercial, service and others).

Figure 4.22 and Figure 4.23 show the future trends of different fuels energy demanded by all sectors in Burundi and Kenya, respectively. It is clear from these graphs that energy from renewables will still have a lower percentage in the total energy consumed by these countries.



Here, oil refers to "petroleum products" exclusively used in the economic sectors (Agriculture, Transport, Industry, Commercial, service and others)

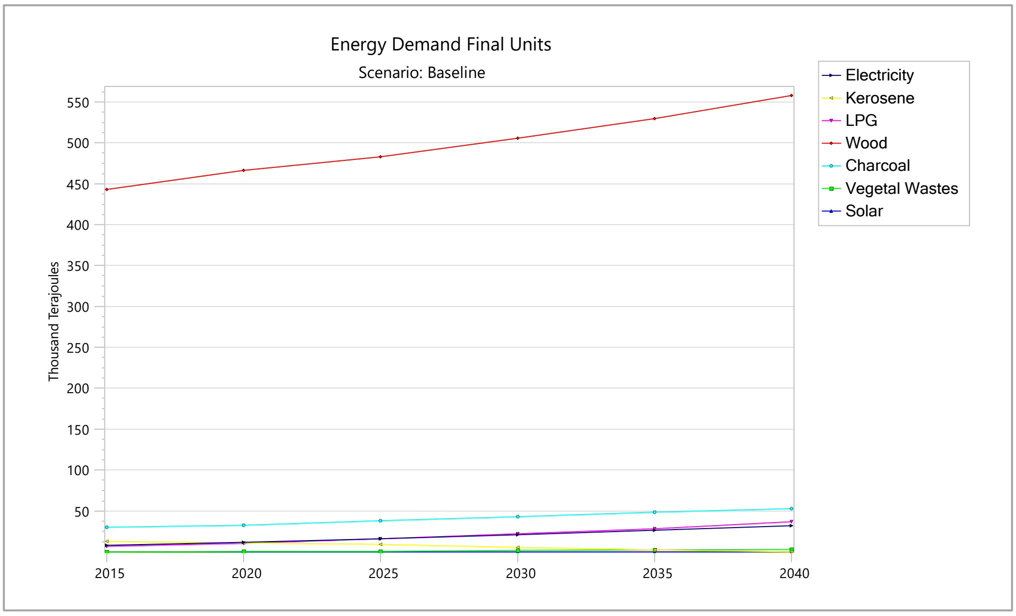
Figure 4.22: Per fuel Total Energy Demand (TJ) for Burundi



Here, oil refers to "petroleum products" exclusively used in the economic sectors (Agriculture, Transport, Industry, Commercial, service and others)

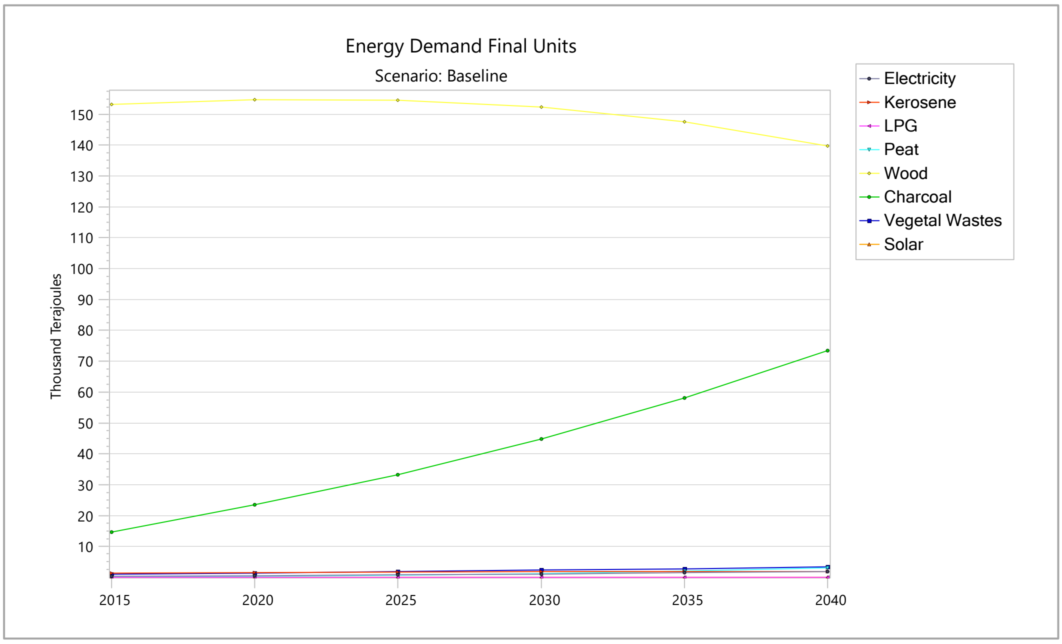
Figure 4.23: Per fuel Total Energy Demand (TJ) for Kenya

The residential sector being the main consumer of total final energy in both countries, it is noticed that all other fuels gathered will remain with lower proportion as compared to Biomass fuels. Figure 4.24 and Figure 4.25 show the trends of energy consumption from Renewables and other fuel types for Kenya and Burundi, respectively.



Note: Here wood refers to firewood

Figure 4.24: Trend of Total Energy Demand by Kenyan Residential Sector



Note: Here wood refers to firewood

Figure 4.25: Trend of Total Energy Demand by Burundian Residential Sector

The graph of Figure 4.26 shows the demanded energy by each sub-sector in the Kenyan urban households. The energy consumption by cooking services will keep increasing and will occupy a high percentage as compared to other sub-sectors. While the total energy demanded by urban households was 68,161.9 TJ in 2015, cooking services only consumed 33,142.8 TJ for electrified households plus 29,539.4 TJ for the non-electrified urban households. The cooking using unimproved stoves is expected to remain the main energy consumer by the Kenyan urban households. Other fuels such as charcoal, LPG and electricity are also expected to increase in terms of energy demand.

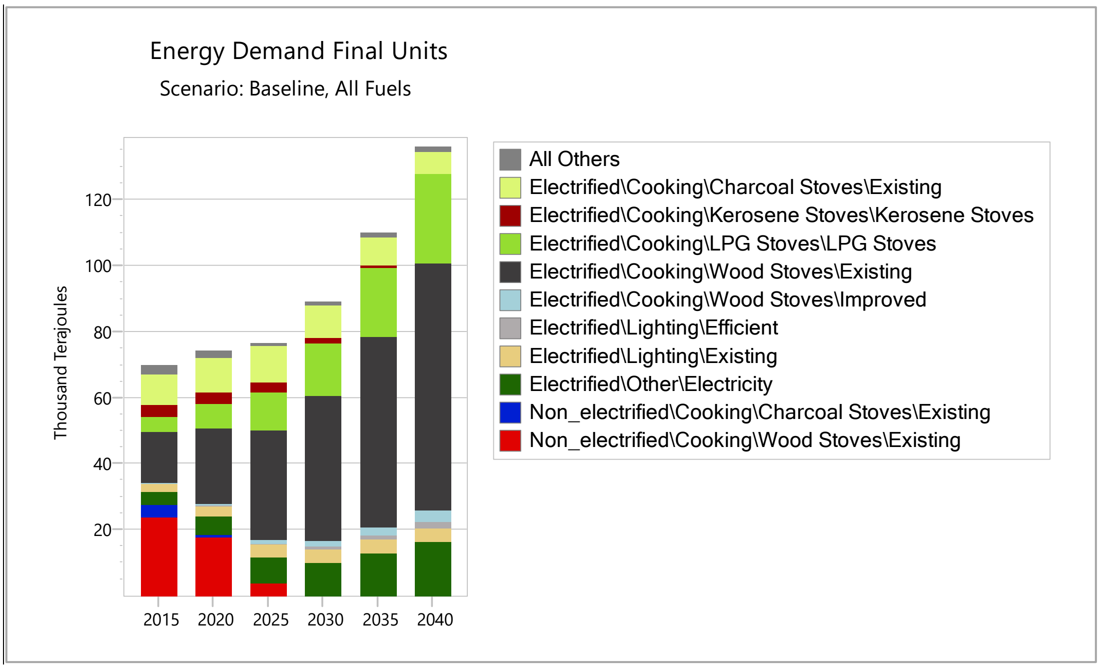


Figure 4.26: Share of Total Energy Demand by Kenyan Urban Households

For the case of the Burundian urban residential sector, the expectations are also similar to the Kenyan case as the cooking services will remain the main consumer of the total energy demanded by urban households. The graph of Figure 4.27 shows the demanded energy by each sub-sector in the Burundian urban households. The energy consumption by cooking services will keep increasing and it is expected to occupy a high percentage as compared to other sub-sectors: it occupied 97.9 % of total energy demanded by

Burundian urban households in 2015 and is expected to slightly decline to 97.8 % by 2040. The total energy demanded by urban households was 14,181.6 TJ in 2015 and cooking services only consumed 13,884.3 TJ. By 2040, the total demand by urban households is expected increase to 56,472.1 TJ.

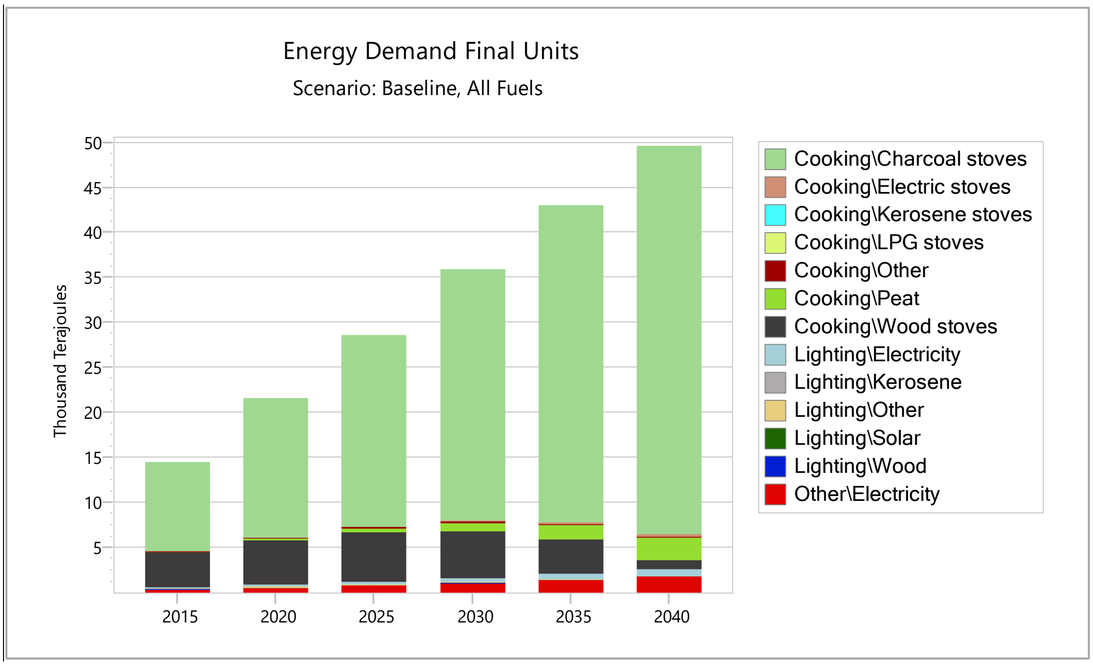


Figure 4.27: Share of Total Energy Demand by Burundian Urban Households

Figure 4.28 and Figure4.29 shows the energy demanded by Kenyan and Burundian rural residential sectors, respectively. Similarly to Kenyan urban residential sector, firewood for cooking will be the main fuel with a high percentage of consumption in the Kenyan rural residential sector (the firewood for cooking occupied 93 % in total energy demanded by Kenyan rural households in 2015 and is expected to decline to 86.7 % in 2040). For the case of Burundi, firewood will be the main fuel with a high energy demand (95.1 % in total energy demanded by Burundian rural households in 2015 and expected to decline to 83.1 % in 2040) in contrast to urban residential sector where it is charcoal (the charcoal fuel for cooking constituted 69.1 % of total energy demanded by Burundian urban households in 2015 and expected to rise up to 90.8 % in 2040).

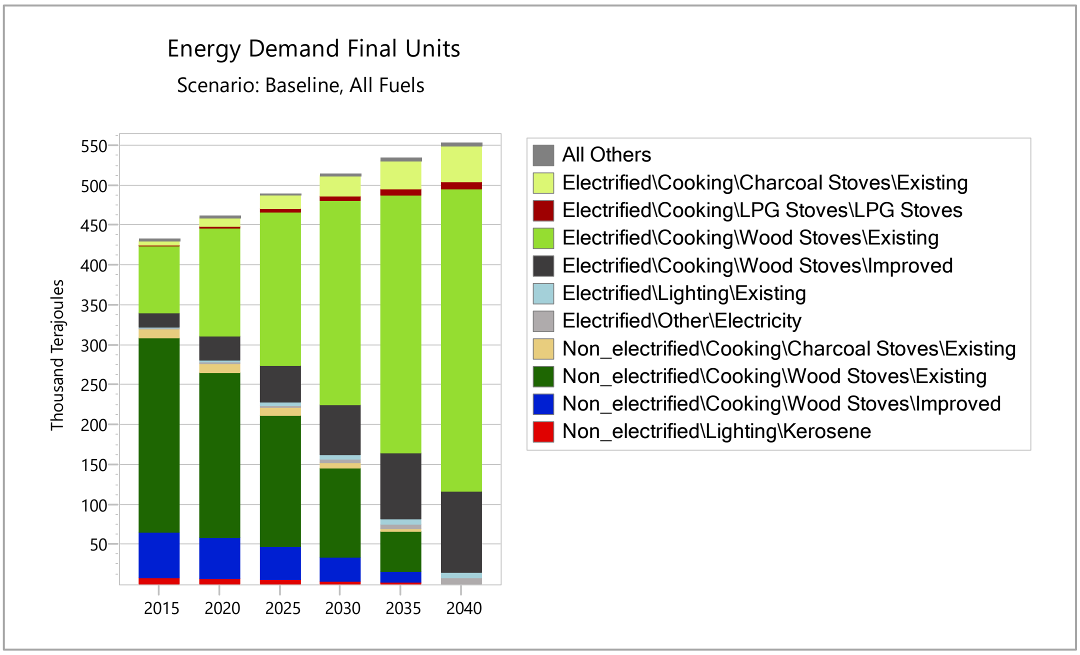


Figure 4.28: Share of Total Energy Demand by Kenyan Rural Households

In both countries, energy required for lighting comes in the second position after cooking. Therefore, it clear that any policy seeking to reduce energy consumption in the Burundi and Kenyan residential sectors will have to focus on how to reduce energy consumed for cooking services and lighting.

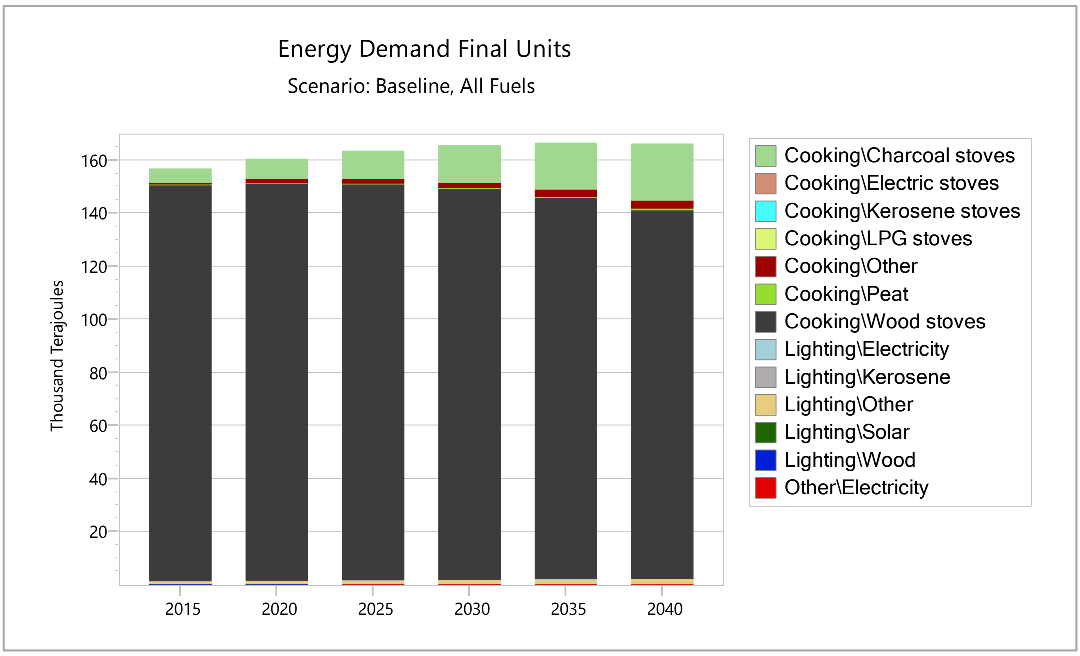


Figure 4.29: Share of Total Energy Demand by Burundian Rural Households

Economic sectors also consume a significant portion of total energy in these countries. In both countries, the transport sector was the main consumer of total energy demanded by the economic sectors in 2015 and is expected to remain the economic sector with a significant energy demand by 2040. The total energy demanded by all Kenyan economic sectors was 184,953 TJ in 2015. From the total, the energy demanded by the transport sector was 113,388.8 TJ representing a share of 61.3 % of the total demanded by the economic sectors. In addition, this sector is expected to remain the main consumer of the total energy demanded by the all sectors with a share of 69.8 % in 2040 followed by industry sector with 29.6 %. Figure 4.30 shows the energy demanded by Kenyan economic sectors.

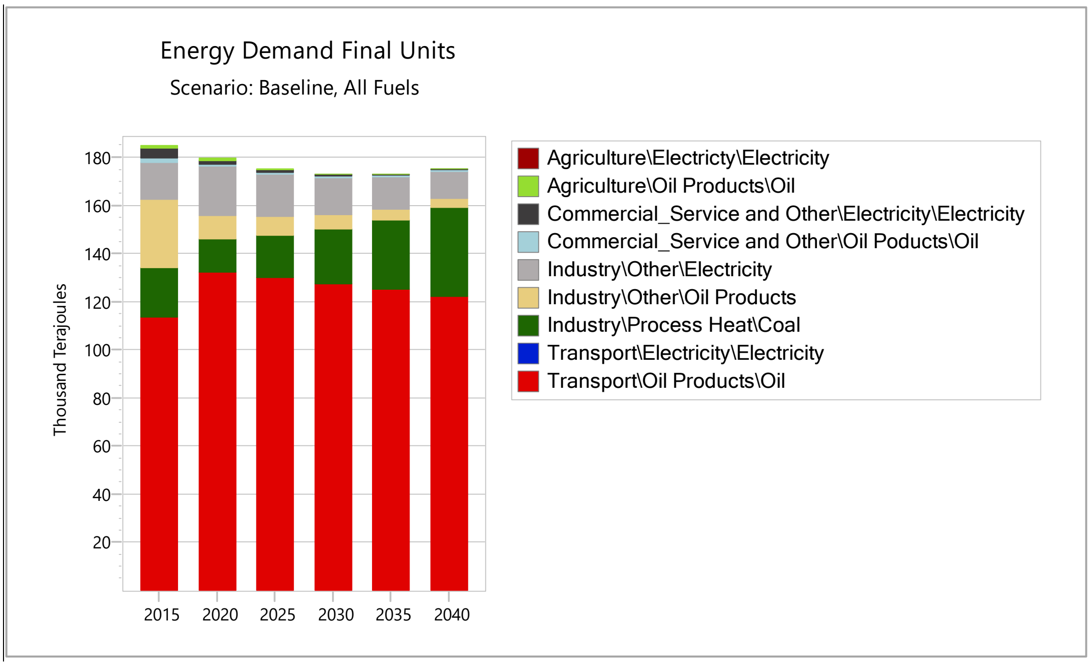


Figure 4.30: Share of Total Energy Demand by Kenyan Economic Sectors

Similarly to Kenyan case, in Burundi, while the total energy demanded by these sectors was 8,229.7 TJ in 2015, the transport sector only consumed 4,781.2 TJ reflecting a consumption of 58.1 % of the total demanded by the economic sectors. In this reference scenario, the transport sector is expected to remain the main consumer of the total energy demanded by these sectors with a share of 66.4 % in 2040. Figure4.31 shows the energy demand by Burundian economic sectors.

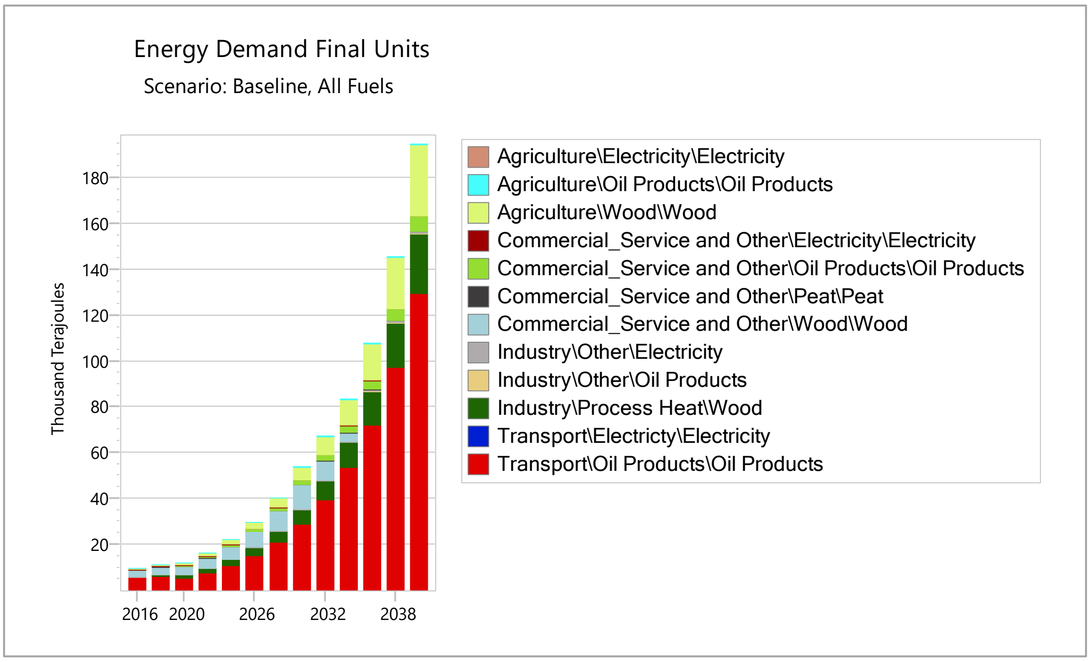


Figure 4.31: Share of Total Energy Demand by Burundian Economic Sectors

Figure 4.32 and Figure 4.33 shows the energy demand per sector in Kenya and Burundi, respectively. Form the graphs, it can be noticed that the agriculture sector consumed less energy as compared to other sectors in both countries. In this reference scenario, the Burundian transport sector is expected to significantly increase its share of energy demand, passing from 4,781.2 TJ in 2015 to 129,150.3 TJ in 2040 whereas the increase is expected to be marginal for the case of Kenya. In addition, as the residential sector will keep demand a high amount of total energy as compared to the other sectors, there rises a need to look at policies able to reduce the energy consumed by this sector, especially that the firewood and charcoal were found to be the main energy demanded by this sector. Hence, the non-action will lead to high deforestation rate.

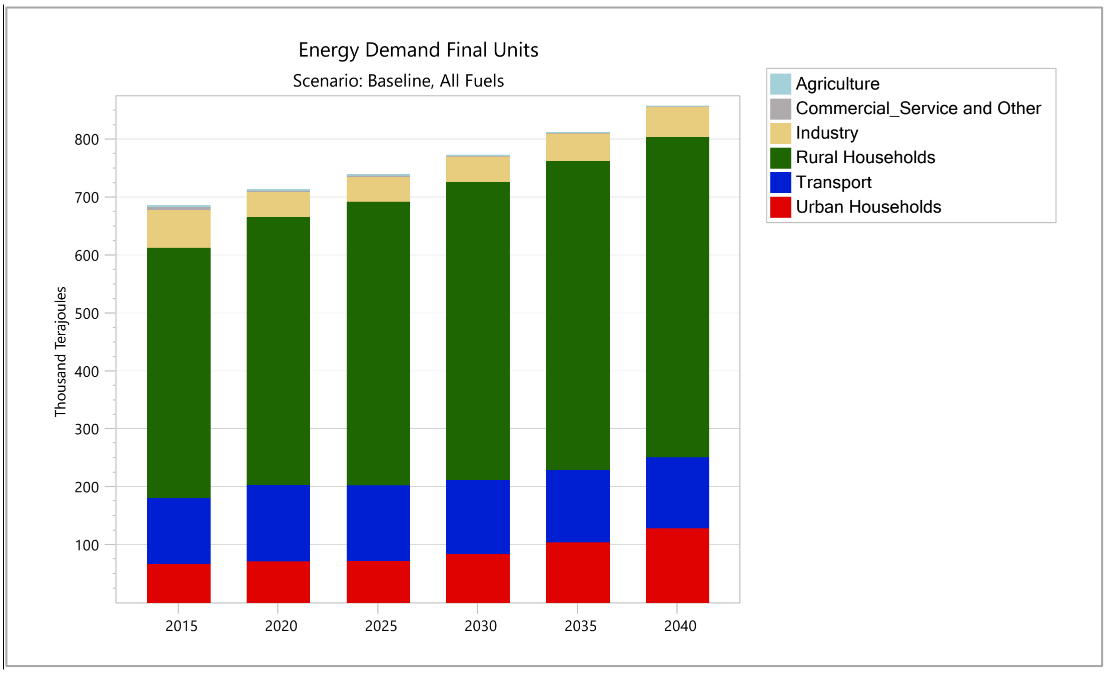


Figure 4.32: Share of Total Energy Demand per Sector (Kenya)

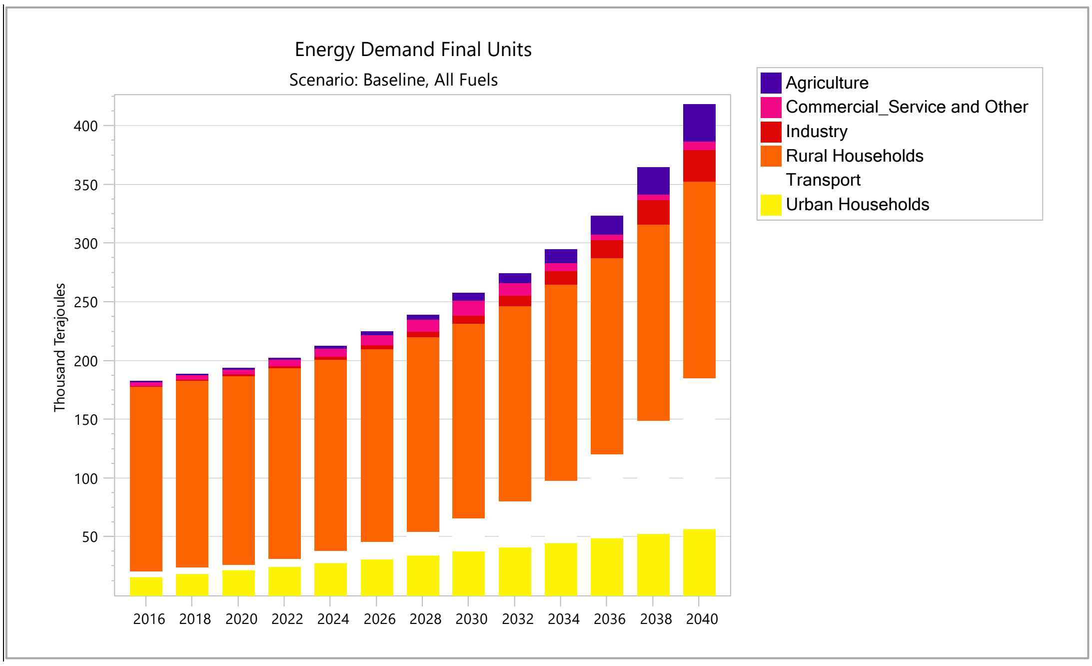


Figure 4.33: Share of Total Energy Demand per Sector (Burundi)

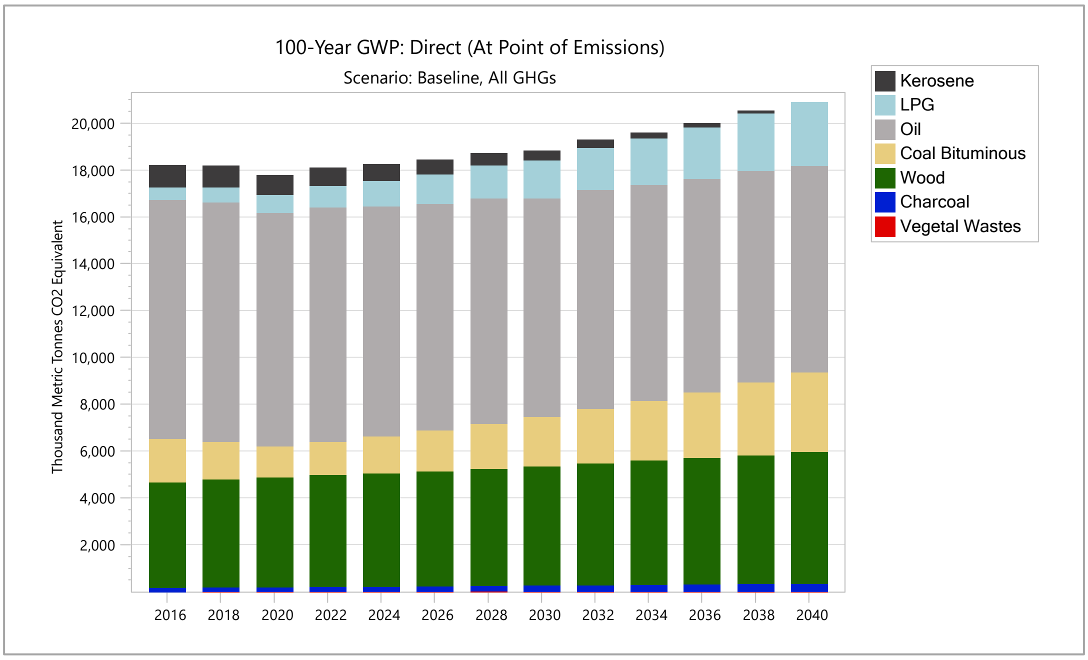
On the other hand, the increase in energy demand is expected to cause the increase in GHG emissions. Simulations of direct emissions (at the point of emissions), measured at 100 – Year GWP "Global Warming Potential" show an rise in CO_2 Equivalent emitted as the energy demand increases. In Kenyan residential sector, they were 6,079.9 Thousand Metric Tonnes (tmt) in 2015 and are expected to rise up to 6,503.7 tmt, 7,375.3 tmt and 8,661.0 tmt by 2020, 2030 and 2040 respectively. Only firewood constituted 73.3 % of the total GHG emissions by the households in 2015 and is expected to remain with a big share of 64.8 % in 2040. Table 4.10 shows the emissions by fuel in the Kenyan residential sector.

Table 4.10: Per fuel GHG Emissions (tmt CO_2 Equivalent) in Kenyan Residential Sector

Fuel	2015	2020	2025	2030	2035	2040
Kerosene	947.7	822.2	651.7	395.3	201.8	-
LPG	487.9	776.7	1,169.7	1,602.4	2,093.1	2,686.8
Wood	4,456.7	4,694.3	4,858.7	5,089.9	5,330.7	5,611.3
Charcoal	187.0	203.9	238.8	271.2	302.5	330.0
Vegetal Wastes	0.7	6.6	7.9	16.4	24.2	32.9
Total	**6,079.9**	**6,503.7**	**6,926.8**	**7,375.3**	**7,952.3**	**8,661.0**

Note: Here, CO_2 Equivalent is an equivalent of the following GHG: Carbone Dioxide, Methane and Nitrous Oxide

In Kenyan total energy demand, oil is the main contributor of GHG emissions with a share of 55.8 % in 2015 and is expected to remain the main contributor by 2040 with 42.2 % of share. The total GHG emissions were 18,125.9 tmt in 2015 and are expected to increase up to 17,788.0 tmt, 18,824.8 tmt and 20,885.8 tmt by 2020, 2030 and 2040 respectively. Figure 4.34 shows the GHG emissions from the Kenyan total energy demand.



Note: Coal**: Coal Bituminous; Oil*: Here, oil refers to "petroleum products" exclusively used in the economic sectors (Agriculture, Transport, Industry, Commercial, service and others).

Figure 4.34: GHG Emissions from Kenyan Total Energy Demand

Therefore, the transport constitutes the main contributor of GHG emissions in total energy demanded in Kenya with 43.4 % of share in 2015. Furthermore, it is expected to remain the main GHG emitter by 2040 with 40.6 % of share as shown by Figure4.35. In agreement to Nyangena, the Kenyan transport sector contributed to about 45 % of CO_2 emitted in Kenya for the year 1999 (Nyangena, 2013).

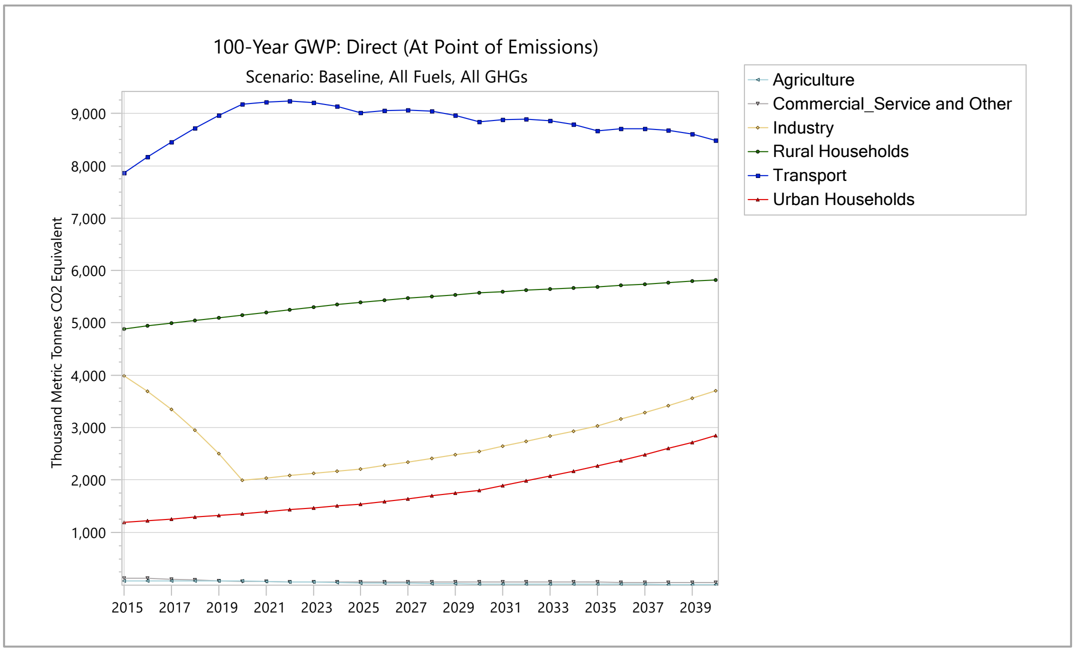


Figure 4.35: Per Sector GHG Emissions from Kenyan Total Energy Demand

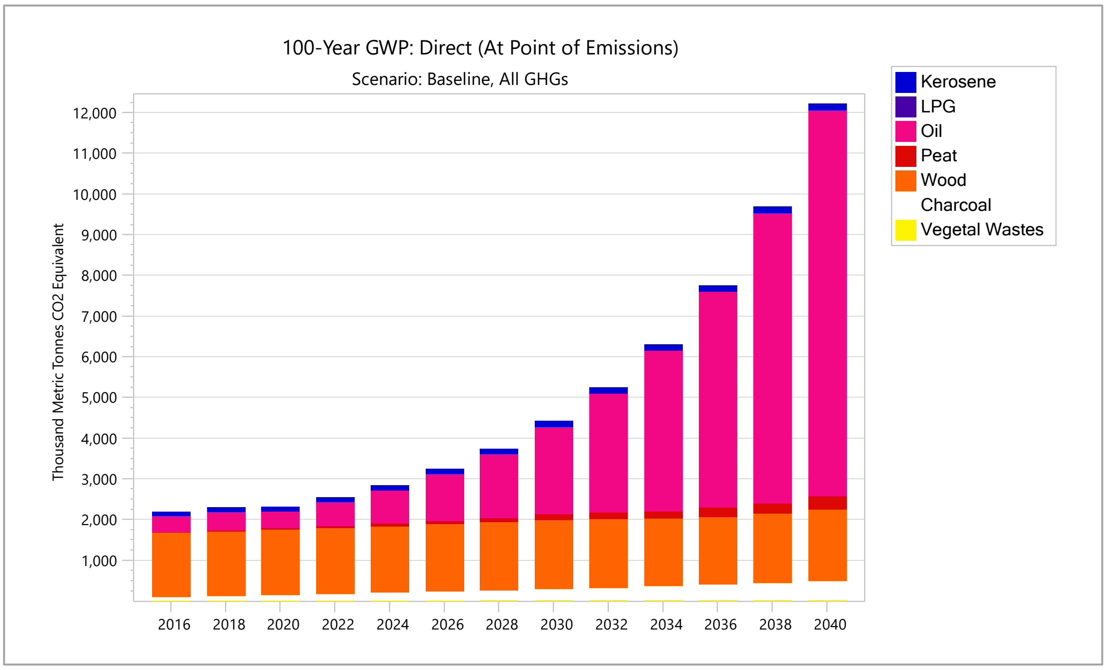
For the case of Burundi residential sector, 1,753.9 tmt CO_2 Equivalent were emitted in 2015 and it is expected that up to 1,859.7 tmt CO_2 Equivalent, 2,095.7 tmt CO_2 Equivalent and 2,358.7 tmt CO_2 Equivalent will be emitted by 2020, 2030 and 2040 respectively. Despite its predicted decline in GHG emissions share, the firewood contributed to 87.8% of the emissions in 2015 and it is expected to remain the main contributor of GHG emissions by 2040 with a share of 59.6 %. Table 4.11 highlights the per fuel GHG emissions by Burundian residential sector.

Table 4.11: Per fuel GHG Emissions (tmt CO_2 Equivalent) by Burundian Households

Fuel	2015	2020	2025	2030	2035	2040
Kerosene	100.7	108.1	119.8	130.9	140.3	142.8
LPG	-	-	-	-	-	-
Peat	10.0	34.7	73.1	129.4	208.6	317.1
Wood	1,540.6	1,555.9	1,554.4	1,531.9	1,483.9	1,405.4
Charcoal	92.0	146.8	208.4	280.3	363.8	459.9
Vegetal Wastes	10.7	14.2	18.5	23.2	28.2	33.5
Total	1,753.9	1,859.7	1,974.2	2,095.7	2,224.7	2,358.7

Note: Here, CO_2 Equivalent is an equivalent of the following GHG: Carbone Dioxide, Methane and Nitrous Oxide

In contrast to the Kenyan case, GHG emitted by wood were with a high share of 73.9 % in 2015 in the Burundian total energy demand. This reflects how the Burundian total final energy demand is highly dependent of biomass. However, in reference scenario, it is forecasted that the situation will change in from 2019 where the share of oil will be 45.4 % against 41.8 % of firewood. About 2,126.2 tmt CO_2 Equivalent of the total GHG were emitted in 2015 and are expected to rise to 2,318.6 tmt CO_2 Equivalent, 4,419.8 tmt CO_2 Equivalent and 12,212.4 tmt CO_2 Equivalent by 2020, 2030 and 2040 respectively. Figure 4.36 shows the per fuel GHG emissions in the Burundian total energy demand.



Note: Oil*: Here, oil refers to "petroleum products" exclusively used in the economic sectors (Agriculture, Transport, Industry, Commercial, service and others).

Figure 4.36: Per fuel GHG Emissions from Burundian Total Energy Demand

As from 2019, the transport sector will constitute the main contributor of GHG emissions in total Burundian energy demand as from 2031 with a share of 48.6 %. Figure 4.37 presents the per sector GHG emissions from the Burundian total energy demand.

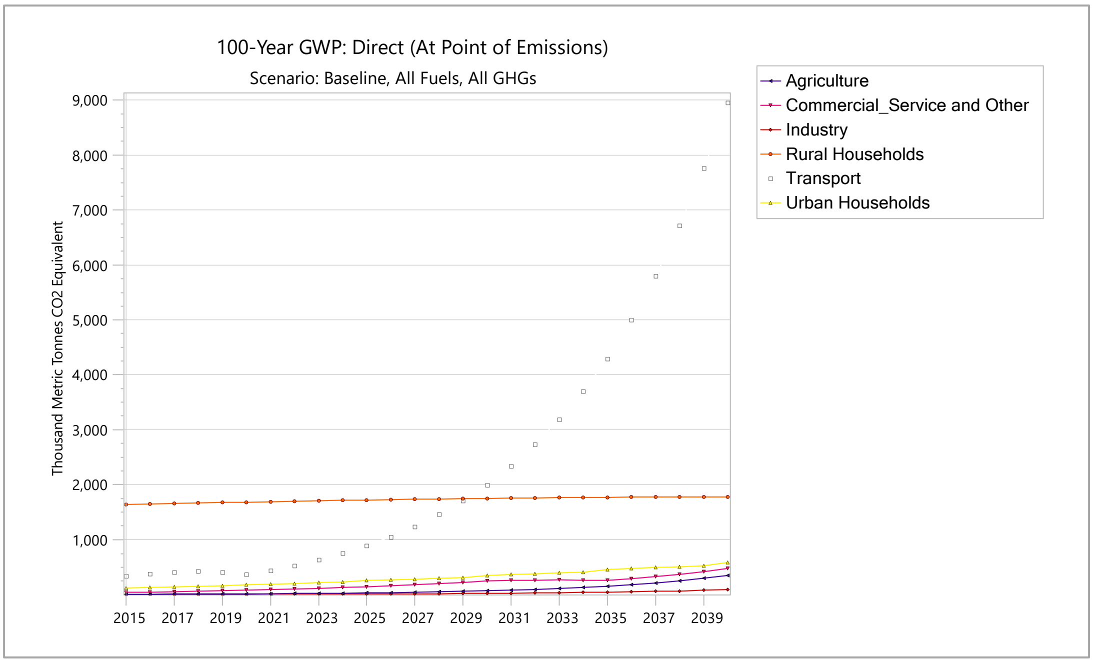


Figure 4.37: Per Sector GHG Emissions from Burundian Total Energy Demand

4.2.3 Current and Future Energy Supply: Reference Scenario

In the reference scenario, the countries energy transformation was built based on their governments' plans. The renewable and fossil fuels were all considered without any restrictions for GHG emissions target.

Figure 4.38 and Figure 4.39 shows the planned expansion plans of electric power plants for Burundi and Kenya, respectively.

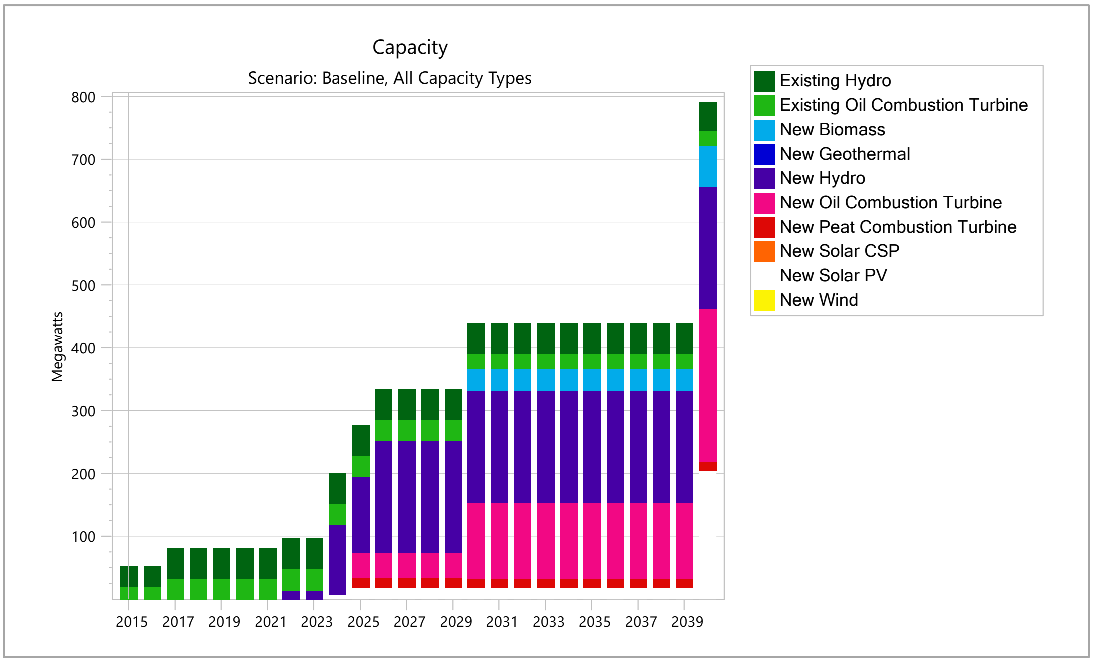


Figure 4.38: Electric Power Plants Installed Capacity-Baseline Scenario (Burundi)

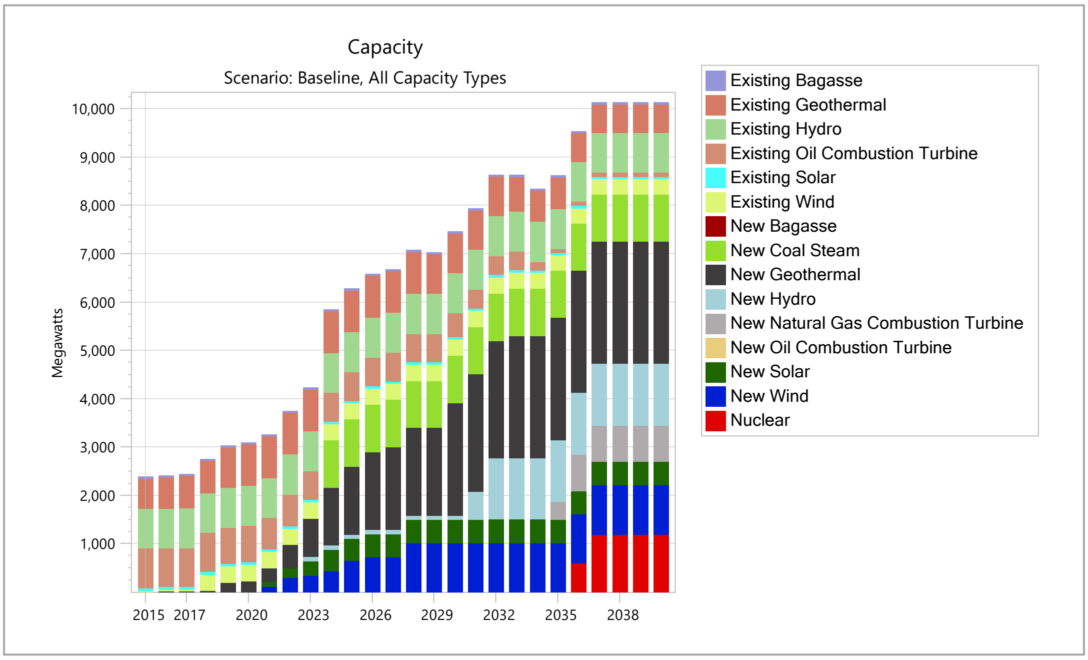


Figure 4.39: Electric Power Plants Installed Capacity - Baseline Scenario (Kenya)

From the two graphs (Figure 4.38 and Figure 4.39), the installed capacities of the power plants will sharply increase for both countries. This was 2,385.8 MW in 2015 for Kenya and is projected to become 3,097.3 MW, 6,281.3 MW, 7,458.3 MW, 8,616.3 MW and 10,136.3 MW in 2020, 2025, 2030, 2035 and 2040 respectively. For the case of

Burundi, the installed capacity was 52 MW in 2015 and is projected to grow up 82 MW, 277.5 MW, 439.5 MW and 790 MW to in 2020, 2025, 2030 and 2040, respectively.

Hence, the electricity supply from these power plants will also increase in these countries. The total electricity generation in Kenya was 9,736 GWh in 2015 and this was projected to increase up to 11,173 GWh, 12,091.5 GWh, 12,332 GWh, 13,163.1 GWh and 14,125.4 GWh in 2020, 2025, 2030, 2035 and 2040 respectively. For the case of Burundi, the generation was 137 GWh in 2015 and it was projected to rise up to 216.8 GWh, 404.3 GWh, 511.5 GWh, 706.7 GWh and 982.1 GWh in 2020, 2025, 2030, 2035 and 2040 respectively. Figure 4.40 and Figure 4.41 show the projected electricity supply by different power plant technologies for Burundi and Kenya respectively.

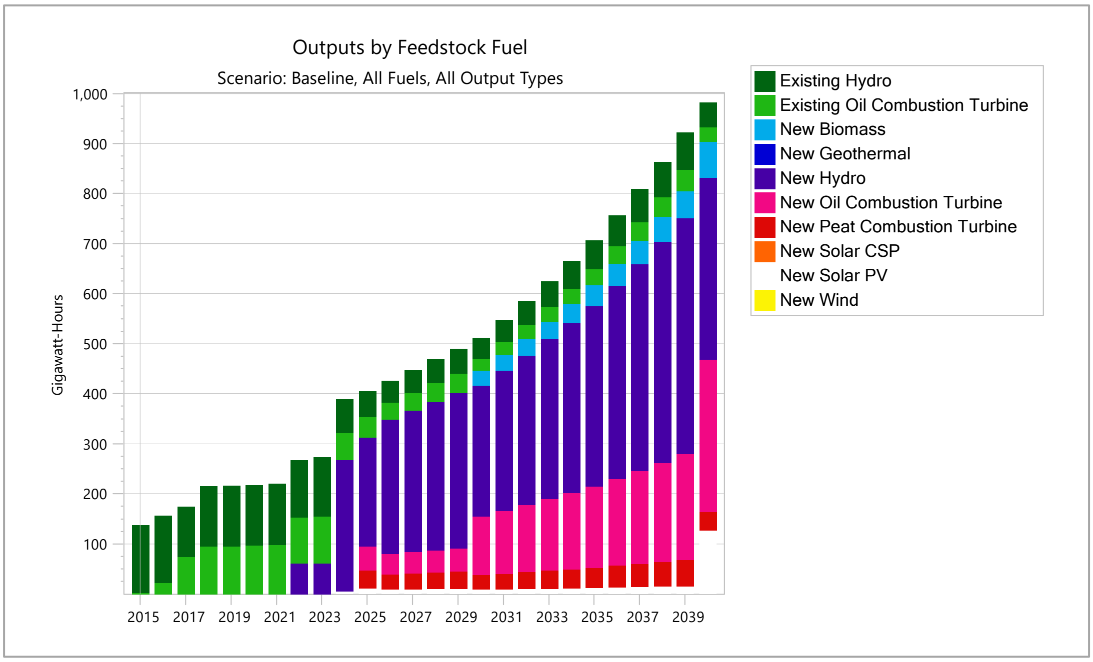


Figure 4.40: Total Electricity Supply by Plant - Baseline Scenario (Burundi)

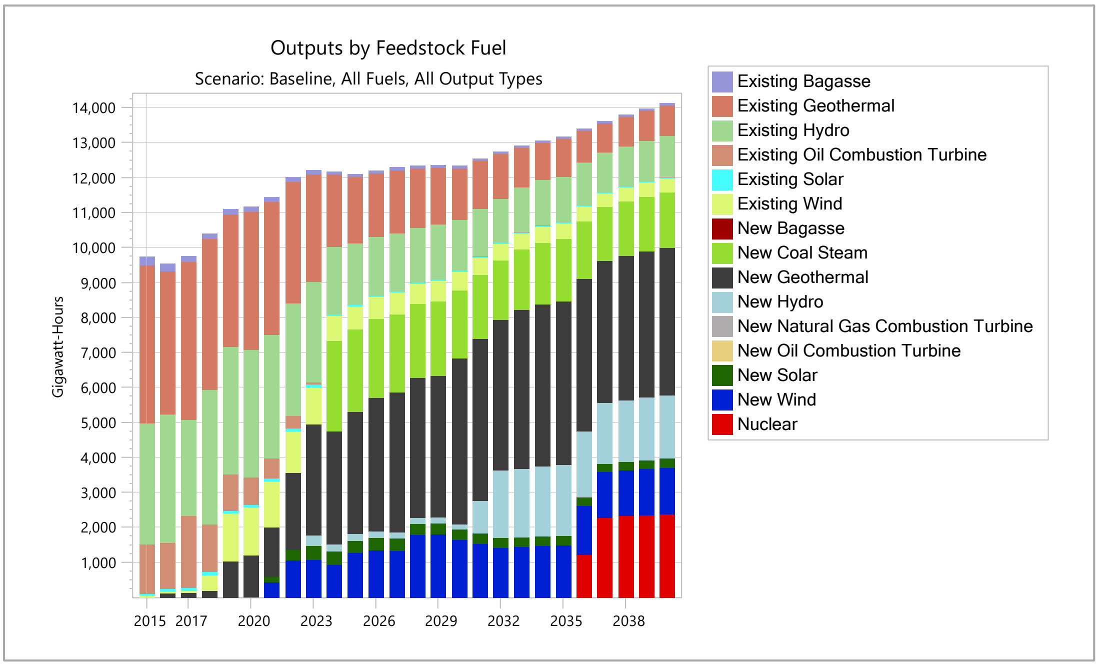


Figure 4.41: Total Electricity Supply by Plant - Baseline Scenario (Kenya)

During the study period, some power plants were expected to play an important role in the total energy generation. From the different power plant technologies in Kenya, energy generated by geothermal power plants will contribute to a significant share. This is the result of construction of new geothermal power plants in the Kenyan power expansion plan where the new geothermal would contribute to 29.8 % of share by 2040, followed by Nuclear (16.8 %), new hydro (12.8 %) and new coal (11.2 %) power plants, respectively. However, the shares from geothermal and hydro power plants are projected to drop as they were 46.4 % and 35.6 % in 2015 for existing geothermal and existing hydropower plants respectively due to the high contribution coming from the newly constructed coal and nuclear power plants. During the study period, there are no new bagasse, new natural gas and new oil combustion power plants planned for construction and hence, their shares are 0 %. Figure 4.42 shows the Kenyan electricity supply share (in percentage) by source for the baseline Scenario.

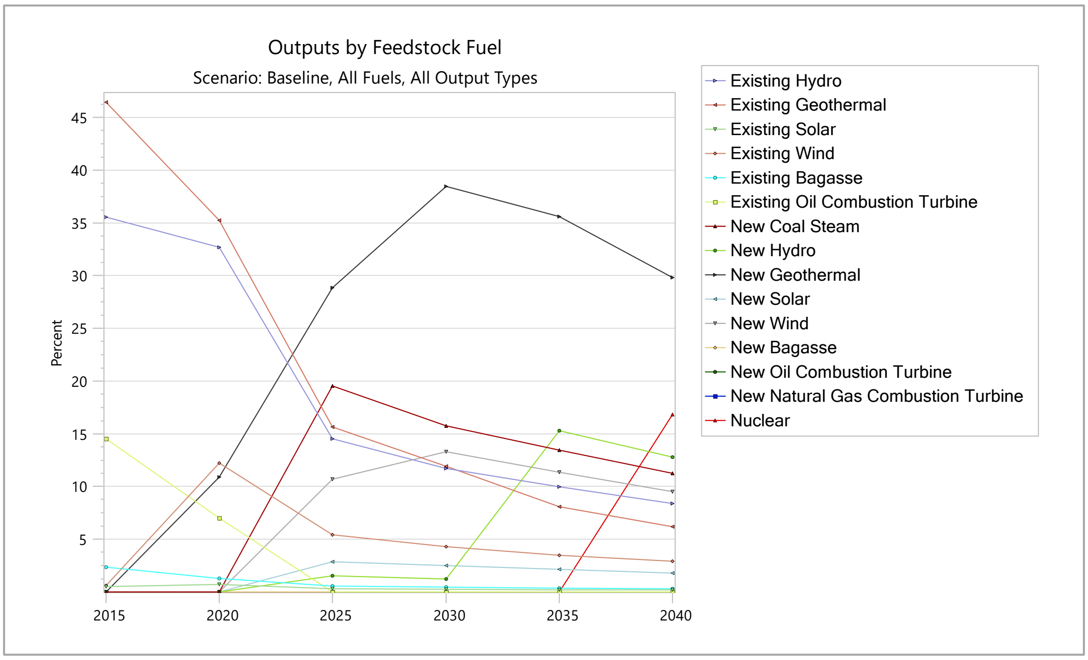


Figure 4.42: Electricity Supply Share (%) by Source - Baseline Scenario (Kenya)

For the case of Burundi, the existing hydropower constituted 97.8 % of the total electricity generation in 2015. In 2040, the new hydropower was projected to play a significant impact in Burundian electricity supply with share of 37.0 % followed by new oil combustion power plants (31.0 % of share). There are no new CSP, wind and geothermal power plants planned for construction during the study period. Hence, their shares would remain 0 % during the study period. Figure 4.43 shows the Burundian electricity supply share (in percentage) by source for the baseline Scenario.

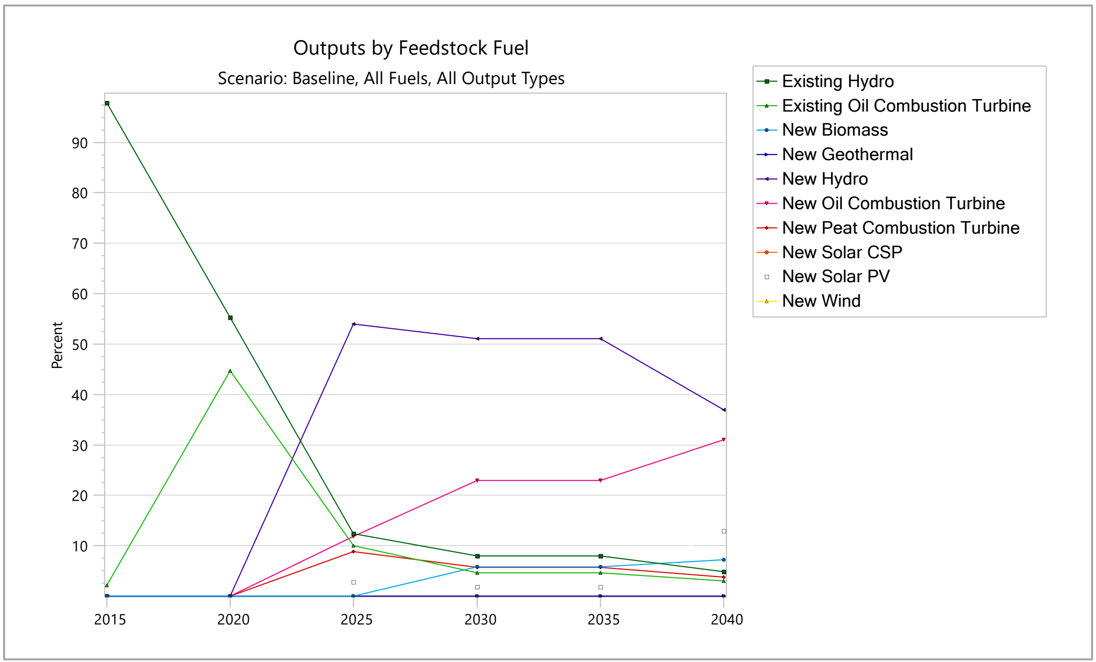


Figure 4.43: Electricity Supply Share (%) by Source - Baseline Scenario (Burundi)

The generation of electricity from fossil fuels are subject to following the GHG emissions. The GHG emissions expressed in CO_2 Equivalent at 100 – Year GWP (at point of emissions) show that 1.9 tmt CO_2 Equivalent were emitted by oil fuelled power plants in 2015 and they are projected to reach 89 tmt CO_2 Equivalent, 161.5 tmt CO_2 Equivalent and 249.2 tmt CO_2 Equivalent in 2025, 2035 and 2040 respectively, emitted by oil, biomass and peat fueled power plants. Most of the emissions come from the oil fueled power plants despite a marginal share coming from peat and biomass fired power plants. Figure 4.44 shows the trend of projected GHG emissions from the Burundian electric power generation.

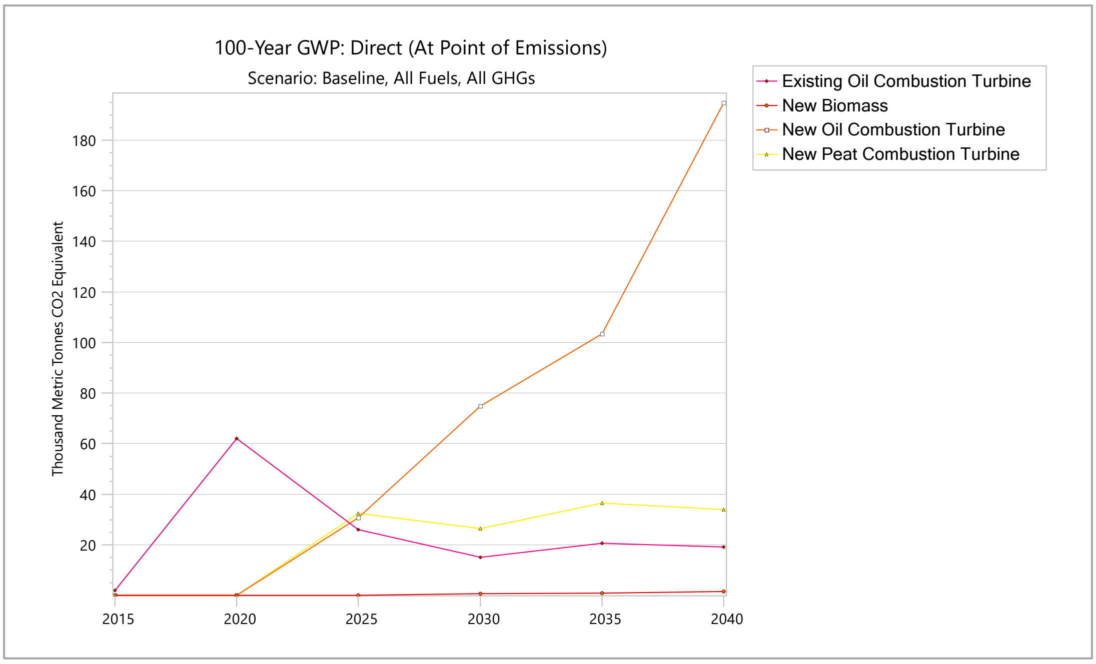


Figure 4.44: GHG Emissions from Electric Power Supply (Burundi)

For the Kenyan case, the bagasse and oil fuelled power plants contributed to significant share of GHG emitted in 2015. About 907.2 tmt CO_2 Equivalent of GHG were emitted in 2015 where oil fuelled power plants contribute to 99.5 % of total emissions. These emissions are expected to grow during the study period. They are projected to increase up to 1,840.6 tmt CO_2 Equivalent, 1,378.1 tmt CO_2 Equivalent and 1,238.2 tmt CO_2 Equivalent in 2025, 2035 and 2040 respectively. The new coal fired power plants are expected to be the main GHG emitter with a share of 99.9 % as from 2024 due the generation of the new coal fuelled power plants (Lamu Unit 1, Lamu Unit 2 and Lamu Unit 3) by 2024. Figure 4.45 highlights the GHG emissions from the Kenyan electric power generation during the study period.

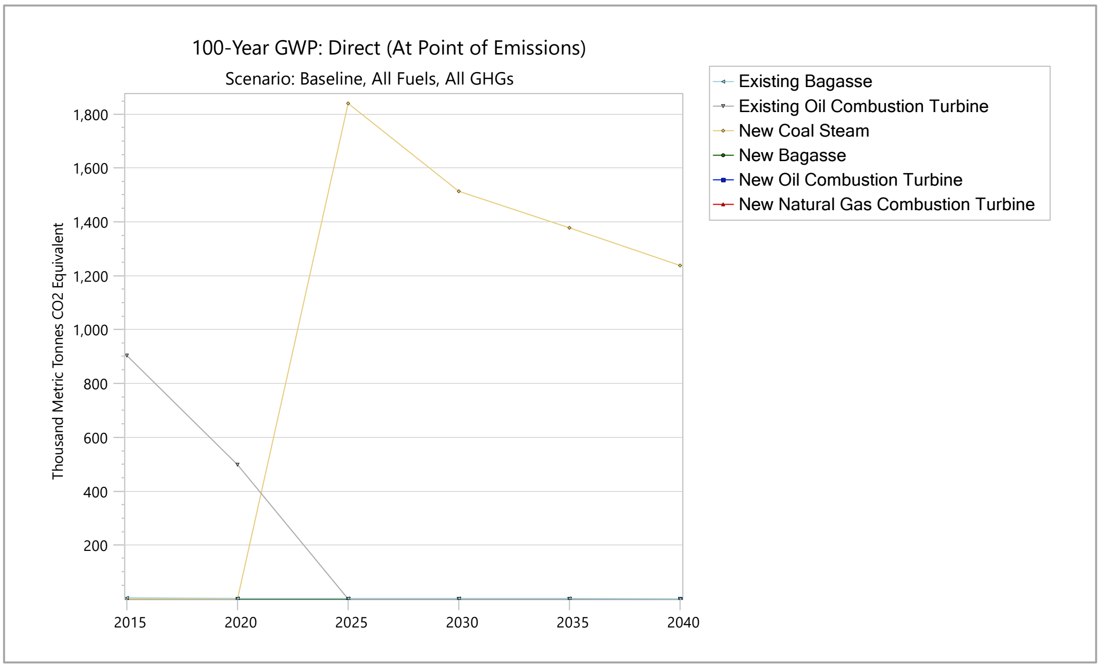


Figure 4.45: GHG Emissions from Electric Power Supply (Kenya)

All the other modules in energy transformation of the two countries (i.e. charcoal production for all the countries and peat mining for Burundi) were modelled by considering that the production will seek to only satisfy the domestic needs. Hence, they are subject to follow the energy demand requirements in the both countries. Hence, the mining of the peat and the production of charcoal is the cause of a significant amount of GHG emissions. While charcoal production is expected to remain the main contributor of GHG emissions in Burundi, the electricity generation would remain the main contributor of GHG emissions for the case of Kenya. Figure 4.46 and Figure 4.47 show the GHG emissions from energy transformation for Burundi and Kenya, respectively.

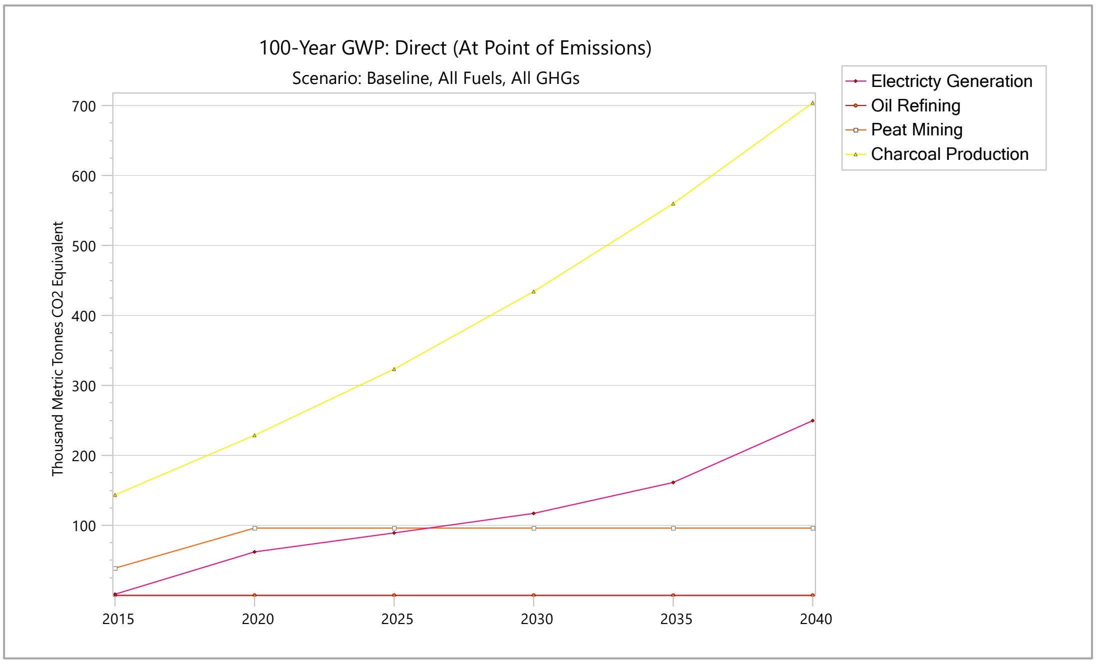


Figure 4.46: GHG Emissions from Burundian Energy Transformation

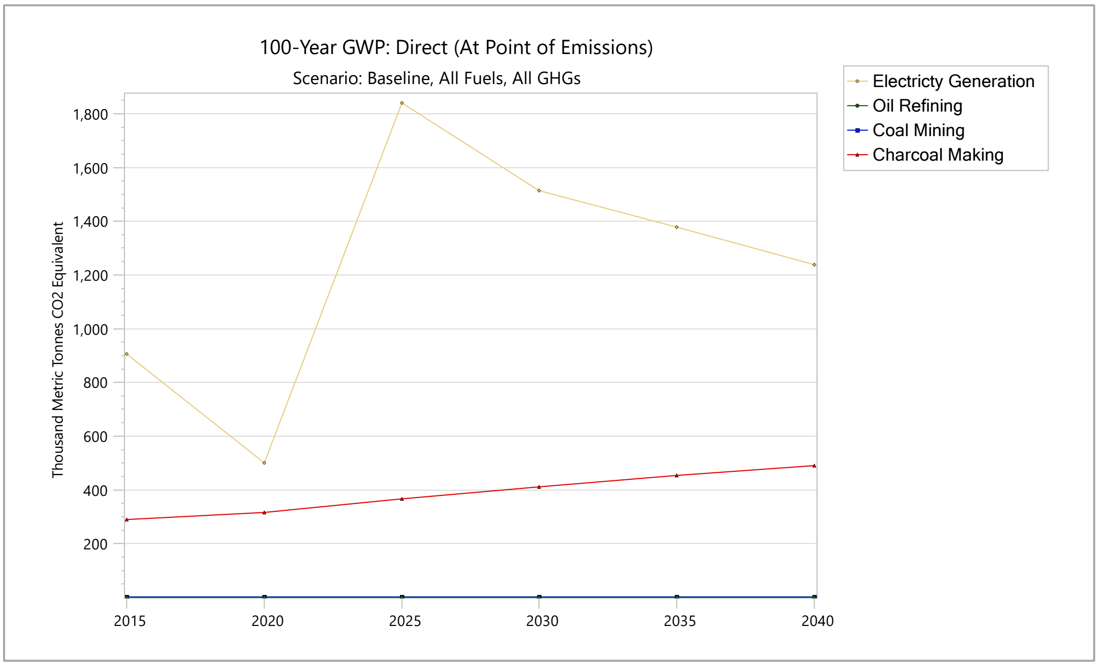


Figure 4.47: GHG Emissions from Kenyan Energy Transformation

After the total energy demand and energy transformation of the countries were determined, the countries' energy balances were constructed. This energy balance was therefore presented in form of graphs called Sankey diagram. Figure 4.48 and Figure 4.49 highlight the Burundian and Kenyan energy balances for the base year (2015) respectively while Figure 4.50 and 4.51 present the Burundian and Kenyan energy balances for the end year 2040 respectively, in the reference scenario.

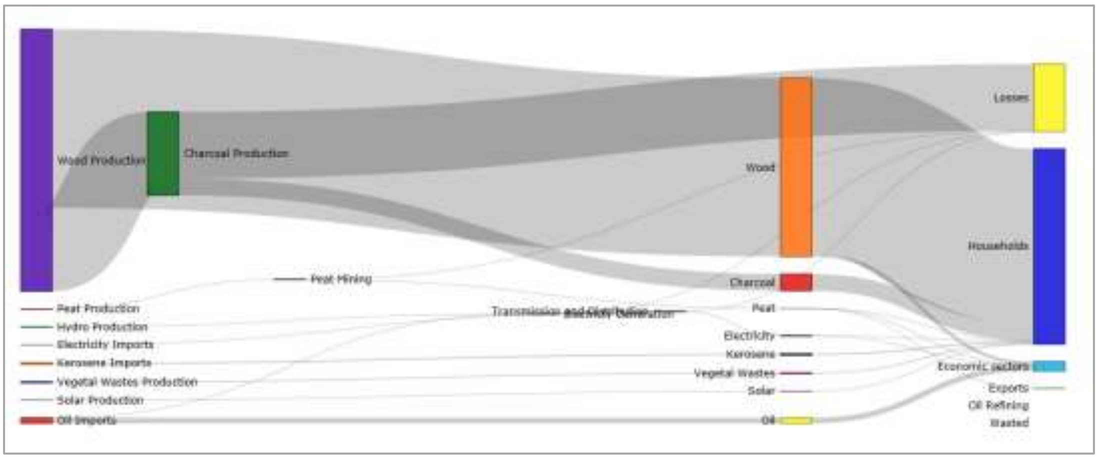


Figure 4.48: Energy Balance in Base Year - Baseline Scenario (Burundi)

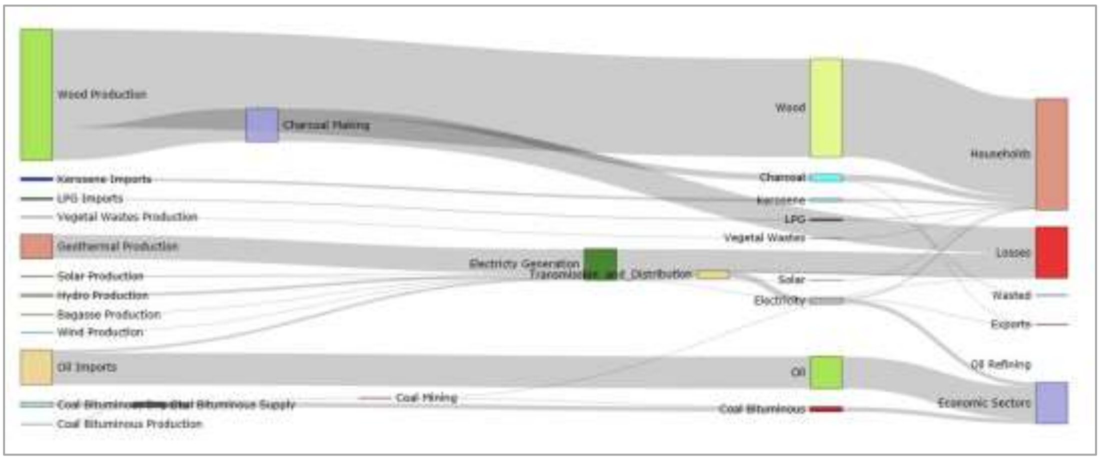


Figure 4.49: Energy Balance in Base Year - Baseline Scenario (Kenya)

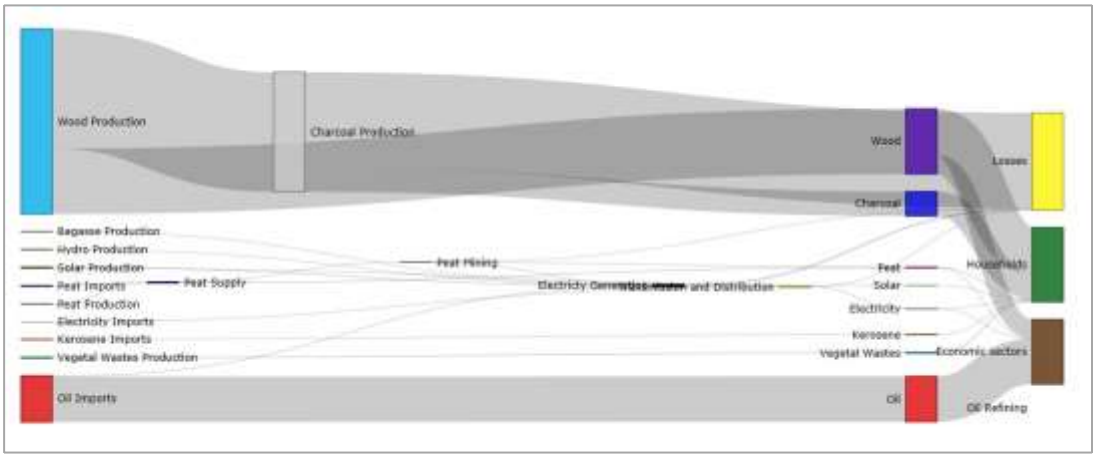


Figure 4.50: Energy Balance in End Year - Baseline Scenario (Burundi)

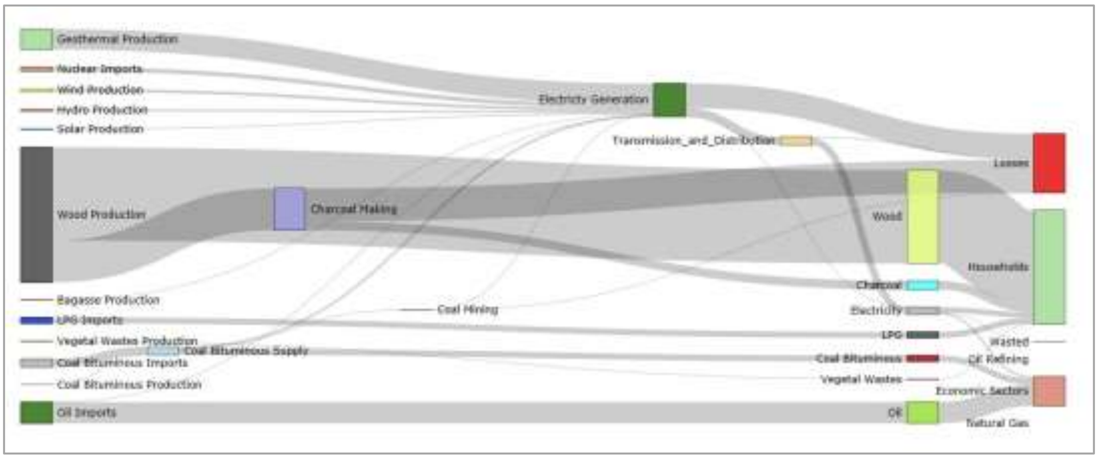


Figure 4.51: Energy Balance in End Year - Baseline Scenario (Kenya)

Based on these graphs (Figure 4.48, Figure 4.49, Figure 4.50 and Figure 4.51), it was noticed that wood fuels play a significant role to satisfy the energy demand by the different sectors of the countries. Furthermore, it can be noticed a significant amount of energy lost during the energy transformation for the both countries. The important losses come from wood transformation for both base and end year and the transformation mainly seeks to satisfy the demand by households in the both countries. Therefore, these Sankey diagrams show the need to reduce the losses which would reduce the total energy generation. For instance, the Burundian Government estimated electric transmission and distribution losses of 13.53 % of total electricity produced in 2014 against 22.14 % in 2013 (Ministry of Energy and Mining, 2015) and huge losses due to the use of inefficient biomass cooking stoves (Ministry of Energy and Mining, 2013) which resulted in losing 40 % of its forest cover between the years 1990 and 2010 (Aera, 2021). For Kenya, about 1,624 GWh and 2,724 GWh were lost due poor electric transmission and distribution, representing 17.5 % and 23.7 % of total energy purchased in 2015 and 2019, respectively (The Kenya Power and Lighting Company, 2019).

4.3 Alternative Energy Policies Analysis

The alternative energy policies were built based on baseline scenario. The baseline scenario was the reference for performing the analysis of different policies.

4.3.1 Efficient Lighting (EL)

The policy of efficient lighting would enable the countries to save a huge amount of energy as compared to the reference scenario. Energy savings by the implementation of this policy are highlighted by Figure 4.52 (for the case of Kenya) and Figure 4.53 (for the case of Burundi). This policy would enable to save up to 203.3 GWh, 1,806.3 GWh and 2,300.9 GWh by 2020, 2030 and 2040 for Kenya respectively and up to 2.5 GWh, 40.5 GWh and 124.6 GWh by 2020, 2030 and 2040 for Burundi, respectively. The residential electricity demanded by households would decline to 6,595.7 GWh by 2040 as compared to 8,896.5 GWh in reference scenario for Kenya case. Similarly, the electricity demanded by Burundian households would decline to 785.7 GWh by 2040 as compared to 910.3 GWh for reference scenario. Therefore, these results suggest that the implementation of this policy is the enabler key for electricity demand reduction in the residential sectors of the countries.

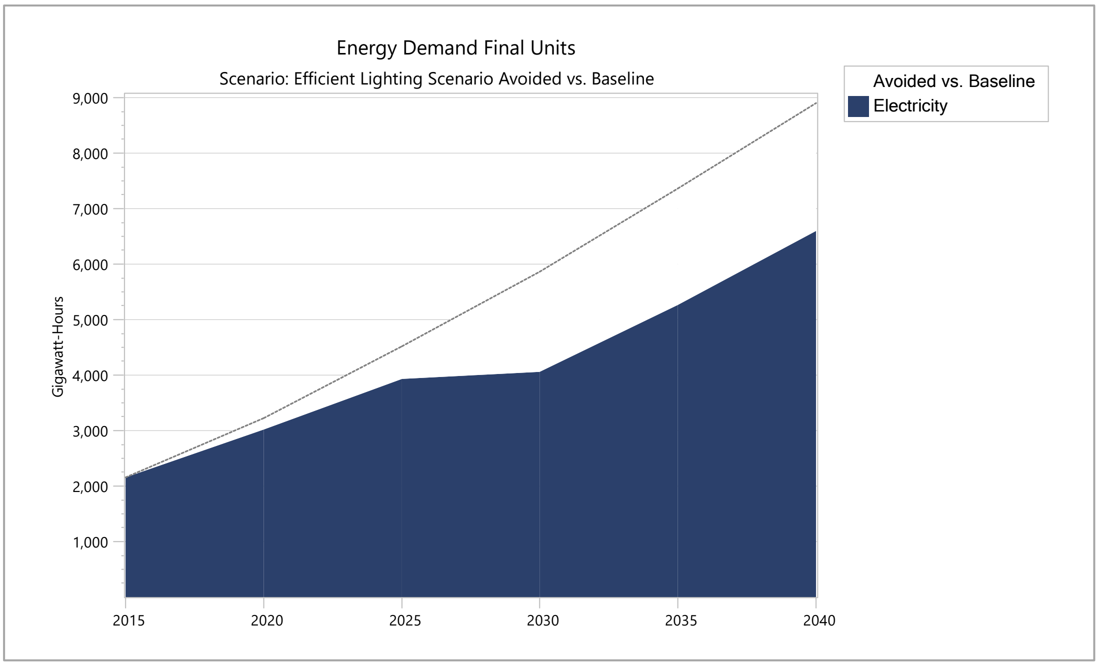


Figure 4.52: Household's Energy savings by Efficient Lighting (Kenya)

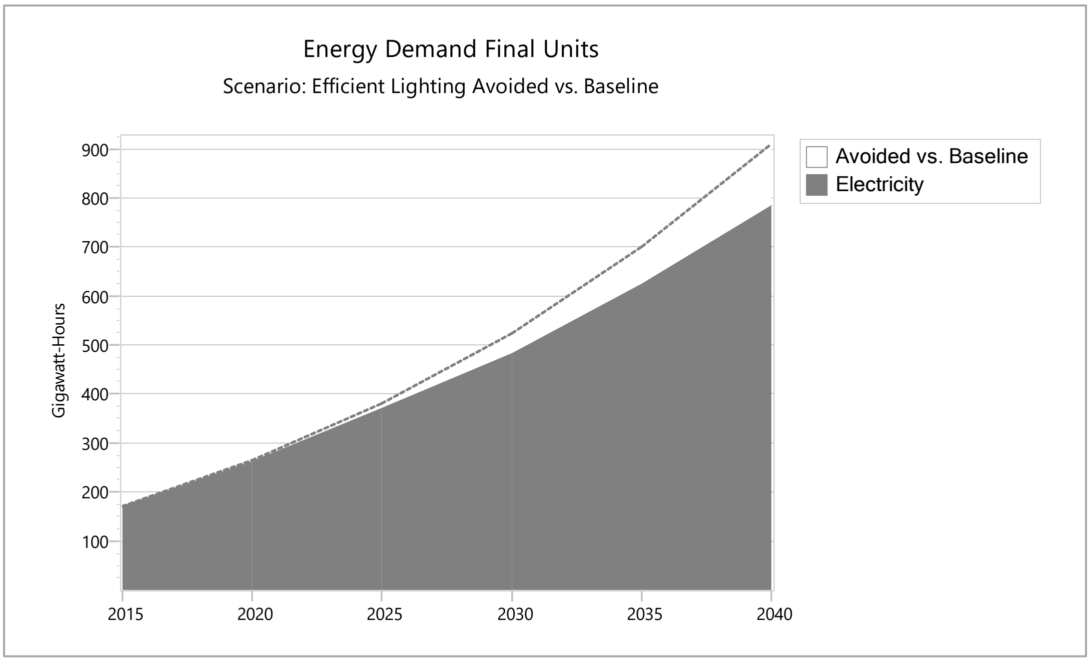


Figure 4.53: Household's Energy savings by Efficient Lighting (Burundi)

The reduction in total electricity demand will effectively influence the reduction of energy generated to satisfy the energy demand. These reductions are in the same order as for the energy demand. Therefore, there is significant amount of GHG emissions which would be reduced from the electricity generation by the implementation of this policy. The emissions were determined in CO_2 equivalent, measure at 100 – Year GWP (At the point of emissions).

By this policy, it was expected that the Burundian total electricity supply would avoid about 0.2 tmt CO_2 equivalent in 2020 and the reductions would keep increasing to reach 10.6 tmt CO_2 Equivalent and 35.8 tmt CO_2 equivalent in 2030 and 2040, respectively. For the case of Kenya, about 35.4 tmt CO_2 equivalent would be avoided in 2020 and it was expected that 265.3 tmt CO_2 Equivalent and 234.5 tmt CO_2 equivalent would be avoided in 2030 and 2040 respectively. Figure 4.54 and Figure 4.55 present the GHG emissions avoided in total electricity supply by the efficient lighting policy for Burundi and Kenya, respectively.

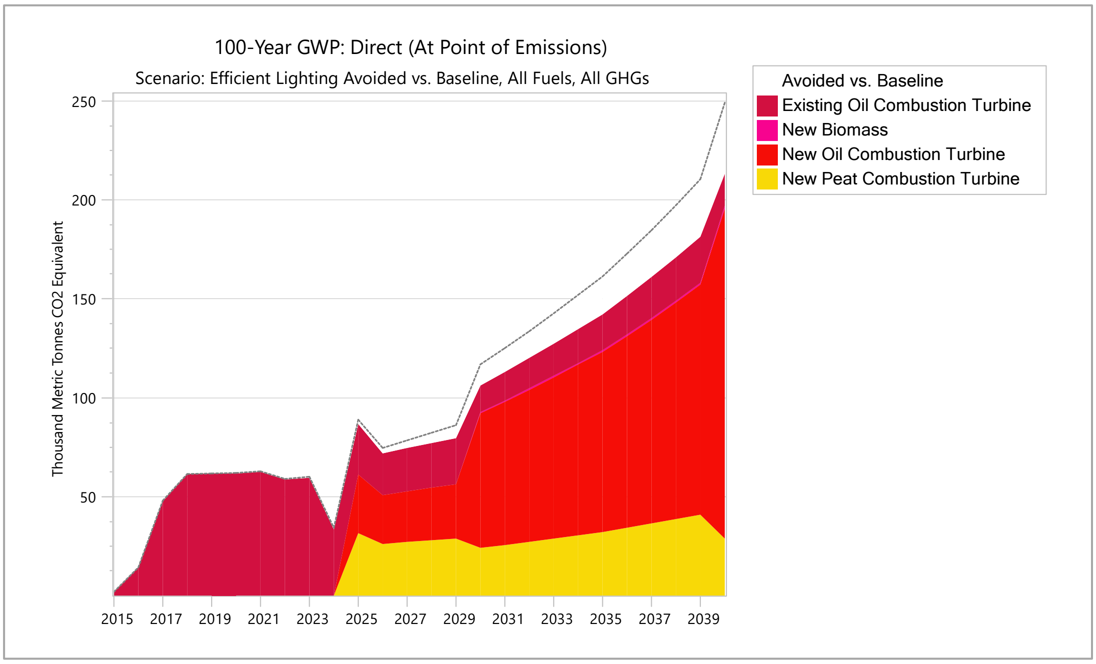


Figure 4.54: GHG Emissions Avoided in Burundian Total Electricity Supply - Efficient Lighting

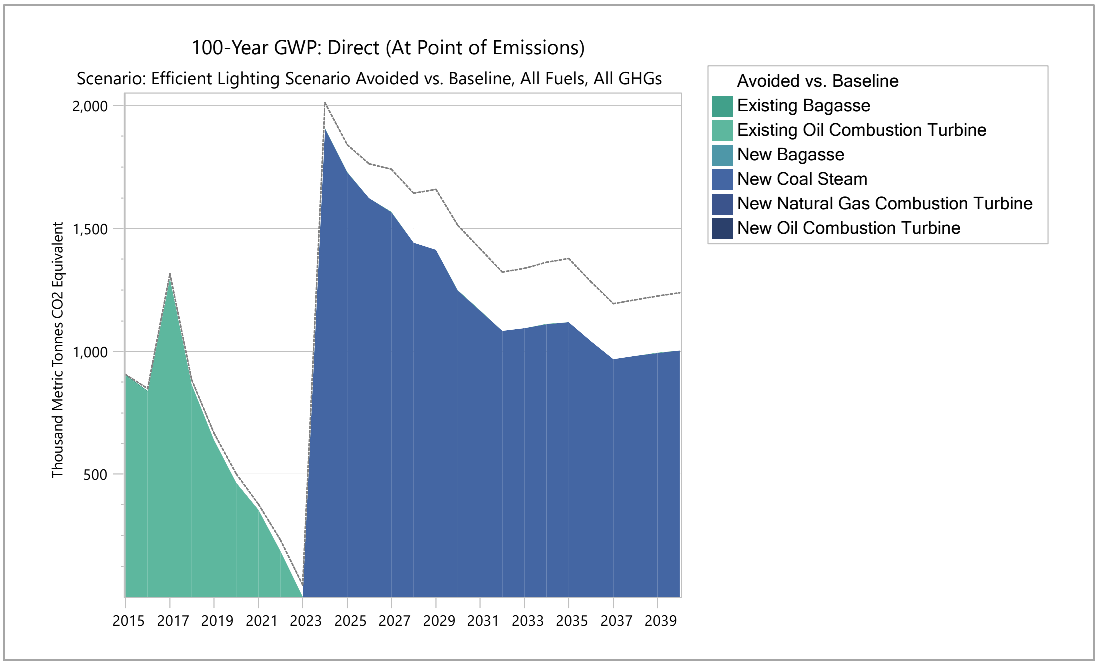


Figure 4.55: GHG Emissions Avoided in Kenyan Total Electricity Supply - Efficient Lighting

4.3.2 Efficient Cooking Stoves (EFCS)

Once the Efficient Cooking Stoves (EFCS) policy implemented, it is expected to save up 35,809.3 TJ, 93,446.3 TJ and 190,556.4 TJ by 2020, 2030 and 2040 respectively for Kenya and up to 21,422.7 TJ, 96,901.2 TJ and 101,879.2 TJ by 2020, 2030 and 2040 for Burundi, respectively. The large proportion of energy savings are resulted from the improved firewood stoves: Savings from firewood are 32,155.8 TJ, 79,235.1 TJ and 156,434.4 TJ by 2020, 2030 and 2040 respectively for Kenya while they are 19,174.6 TJ, 76,065.9 TJ and 69,851.1 TJ by 2020, 2030 and 2040 respectively for Burundi. Figure 4.56 and Figure 4.57 show the energy to be saved by the implementation of this policy for Kenya and Burundi, respectively.

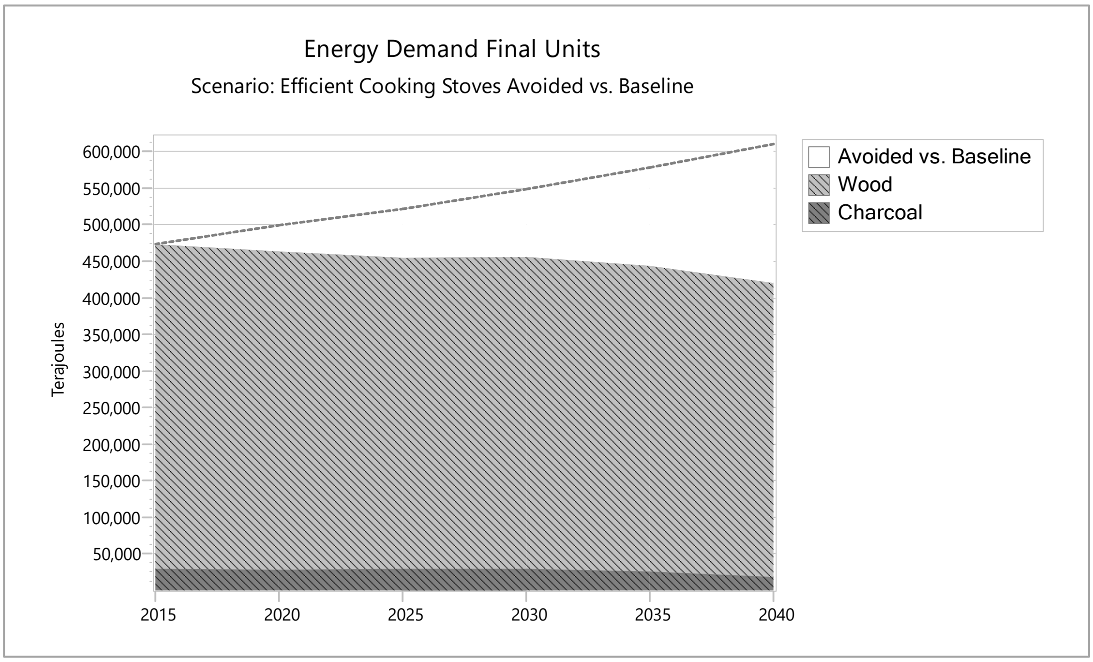


Figure 4.56: Household's Energy savings by Efficient Cooking Stoves (Kenya)

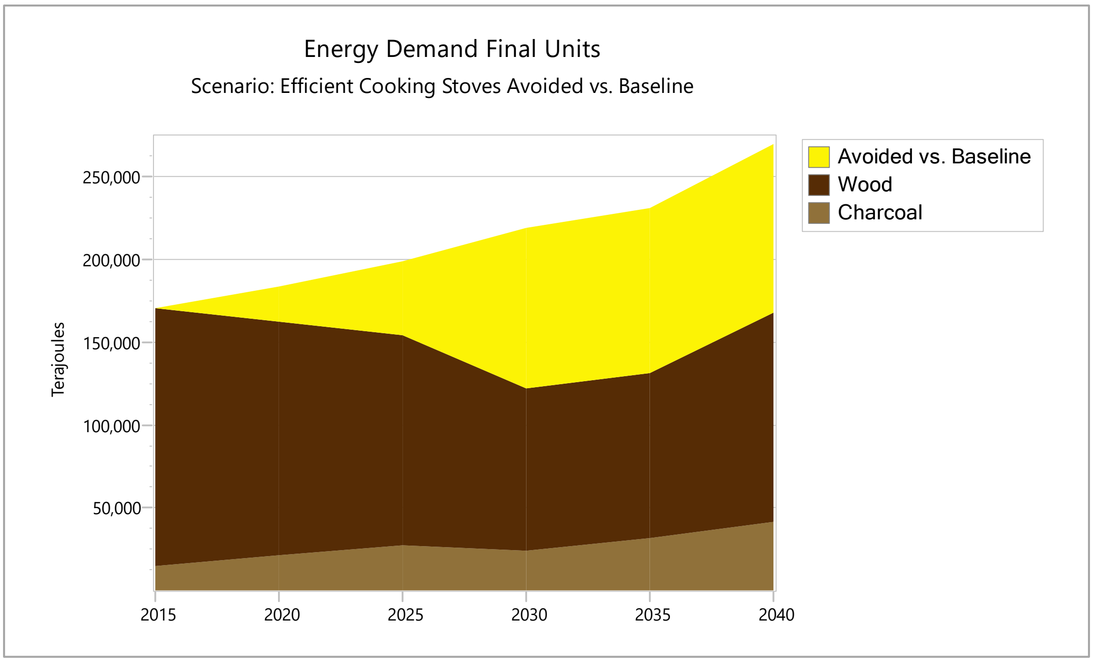


Figure 4.57: Household's Energy savings by Efficient Cooking Stoves (Burundi)

Therefore, this policy would enable the countries to save a huge amount of energy which would result in lower quantities of wood consumption and lower deforestation rate.

Furthermore, this policy is expected to save up 346.4 tmt CO_2 Equivalent, 886.1 tmt CO_2 Equivalent and 1,787.5 tmt CO_2 Equivalent, which would be avoided in comparison to the reference scenario, by 2020, 2030 and 2040 for Kenya, respectively. Table 4.12 presents the avoided GHG emissions (expressed in tmt CO_2 Equivalent) for the Kenyan residential sector by the implementation of the EFCS policy.

Table 4.12: Avoided GHG Emissions (tmt CO_2 Equivalent) by Kenyan Households

Fuel	2015	2020	2025	2030	2035	2040
Avoided vs. Baseline	-	346.4	639.1	886.1	1,268.3	1,787.5
Wood	4,456.7	4,370.8	4,272.0	4,292.8	4,202.7	4,037.5
Charcoal	187.0	181.0	186.4	182.2	162.2	116.2
Total	**4,643.7**	**4,898.2**	**5,097.5**	**5,361.1**	**5,633.2**	**5,941.3**

Note: Here, CO_2 Equivalent is an equivalent of the following GHG: Methane and Nitrous Oxide

For the case of Burundi, it is expected that up to 207 tmt CO_2 equivalent, 895.8 tmt CO_2 equivalent and 903.4 tmt CO_2 equivalent, which would be emitted in reference scenario, by 2020, 2030 and 2040 will be saved, respectively. Table 4.13 presents the avoided GHG emissions (expressed in tmt CO_2 Equivalent) for Burundian households by the implementation of the EFCS policy.

Table 4.13: Avoided GHG Emissions (tmt CO_2 Equivalent) by Burundian Households

Fuel	2015	2020	2025	2030	2035	2040
Avoided vs. Baseline	-	207.0	423.4	895.8	905.9	903.4
Wood	1,540.6	1,363.0	1,169.1	766.7	742.2	702.7
Charcoal	92.0	132.8	170.3	149.8	199.5	259.2
Total	**1,632.5**	**1,702.8**	**1,762.8**	**1,812.2**	**1,847.6**	**1,865.3**

Note: Here, CO_2 Equivalent is an equivalent of the following GHG: Methane and Nitrous Oxide

Therefore, the implementation of this policy is expected to affect the energy transformation. The energy transformed from charcoal production will therefore be reduced. Table 4.14 and Table 4.15 highlight the avoided GHG emissions (expressed in tmt CO_2 Equivalent) from charcoal production for Kenya and Burundi, respectively by the implementation of the EFCS policy.

Table 4.14: Avoided GHG Emissions (tmt CO_2 Equivalent) for Charcoal Production in Kenya – EFCS

Fuel	2015	2020	2025	2030	2035	2040
Avoided vs. Baseline	-	35.6	80.6	135.4	211.0	317.7
Wood	290.9	281.5	286.7	277.1	243.8	172.7
Total	**290.9**	**317.1**	**367.3**	**412.5**	**454.8**	**490.4**

Note: Here, CO_2 Equivalent is an equivalent of the following GHG: Methane and Nitrous Oxide

Table 4.15: Avoided GHG Emissions (tmt CO_2 Equivalent) for Charcoal Production in Burundi – EFCS

Fuel	2015	2020	2025	2030	2035	2040
Avoided vs. Baseline	-	21.9	59.0	201.9	252.7	306.9
Wood	143.1	206.5	264.2	231.7	306.8	396.5
Total	**143.1**	**228.4**	**323.2**	**433.6**	**559.5**	**703.4**

Note: Here, CO_2 Equivalent is an equivalent of the following GHG: Methane and Nitrous Oxide

4.3.3 Universal Electrification (UE)

The implementation of this policy is expected with a high electricity demand in residential sector as shown by Figure 4.58 (Kenya) and Figure 4.59 (Burundi). This is caused by the high number of households being electrified under this policy. Under this policy, the households demand for electricity is expected to be 3,933.9 GWh and 6,845.0 GWh by 2020 and 2030 respectively for Kenya against 3,220.8 GWh and 5,862.5 GWh by 2020 and 2030 respectively under the baseline scenario. Similarly, electricity demanded by the Burundian residential sector is expected to grow up to 158.0 GWh, 399.4 GWh and 825.7 GWh by 2020, 2030 and 2040 while the expectations were 148.3 GWh, 301.2 GWh and 536.5 GWh by 2020, 2030 and 2040 respectively under the reference scenario. This demand would be 982.5 GWh and 98.2 GWh higher than the reference scenario by 2030 for Kenya and Burundi, respectively.

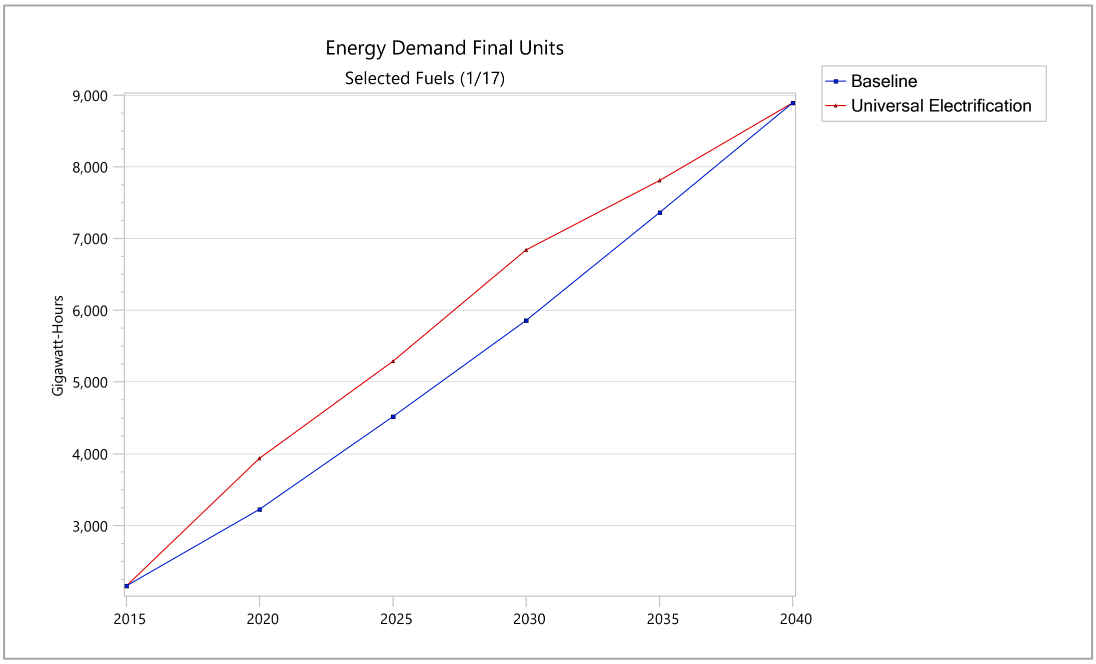


Figure 4.58: Household's Energy demand under Universal Electrification (Kenya)

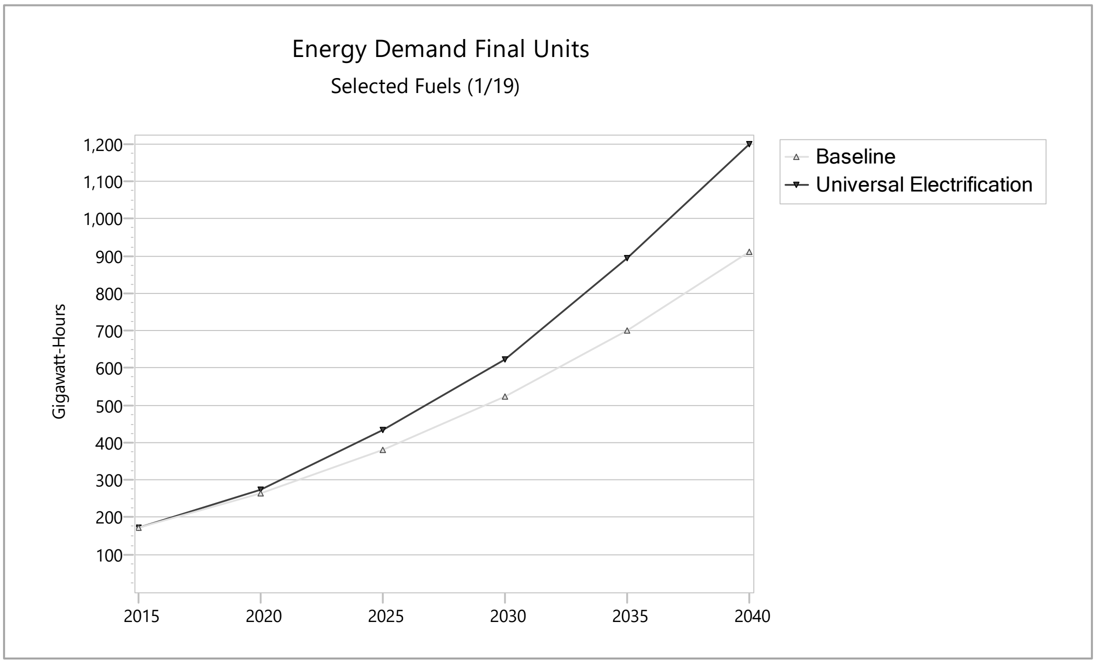


Figure 4.59: Household's Energy Demand under Universal Electrification (Burundi)

Particularly, electricity demanded by rural households would largely grow, reaching 1,999.4 GWh and 3,823.0 GWh by 2020 and 2030 respectively for Kenya while it was 1,406.6 GWh, and 2,840.5 GWh by 2020 and 2030 respectively in the reference scenario. These differences are highlighted by Figure 4.60 and Figure 4.61.

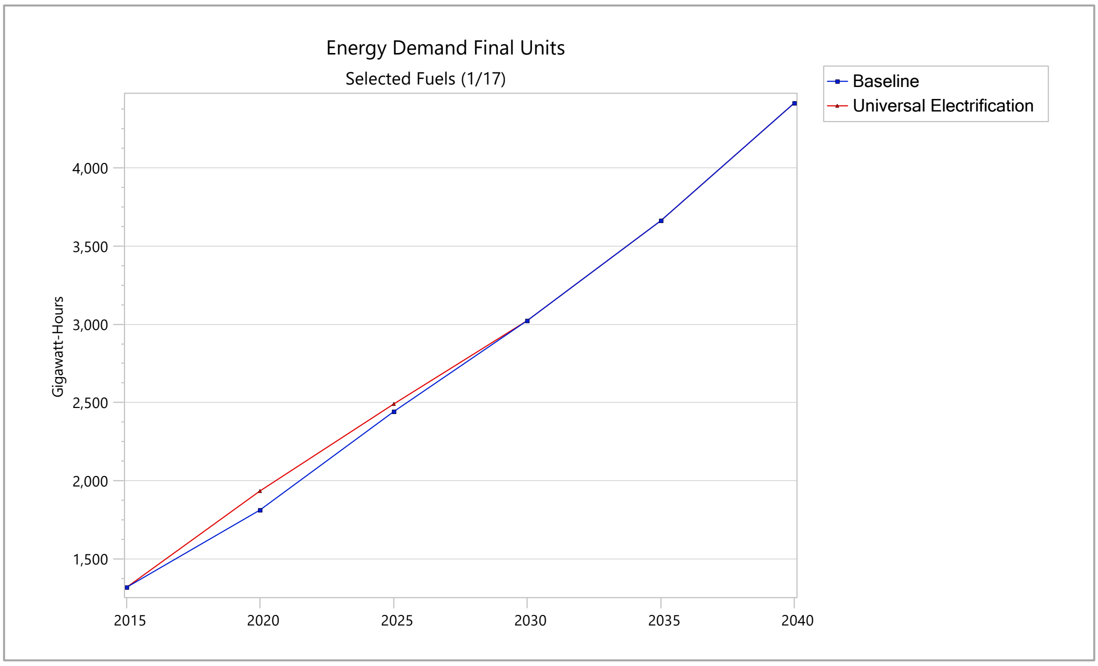


Figure 4.60: Kenyan Urban Household's Electricity Demand under U-E Scenario

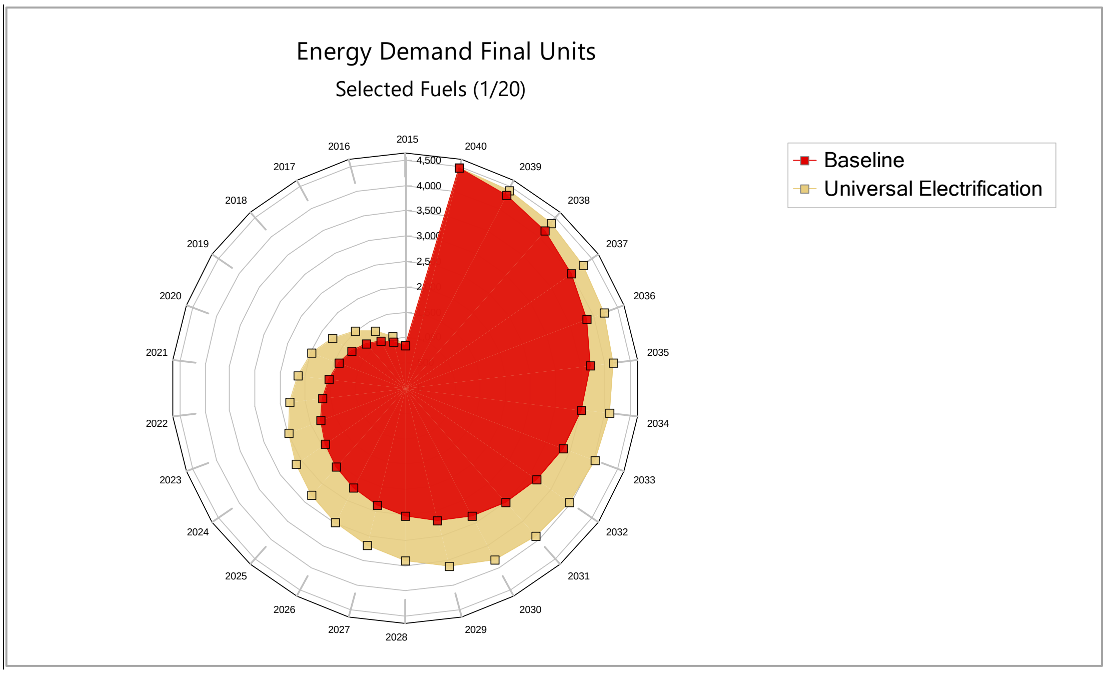


Figure 4.61: Kenyan Rural Household's Electricity Demand (GWh) under U-E Scenario

Similarly, a huge consumption is expected for the Burundian rural residential sector as the demand is expected to become 116.4 GWh, 173.2 GWh, 288.5 GWh and 405.4 GWh by 2025, 2030, 2035 and 2040 respectively against 75.4 GWh, 88.8 GWh, 102.7

GWh and 117.0 GWh by 2025, 2030, 2035 and 2040 respectively under the reference scenario. These differences are highlighted by Figure 4.62 and Figure 4.63 for Burundi.

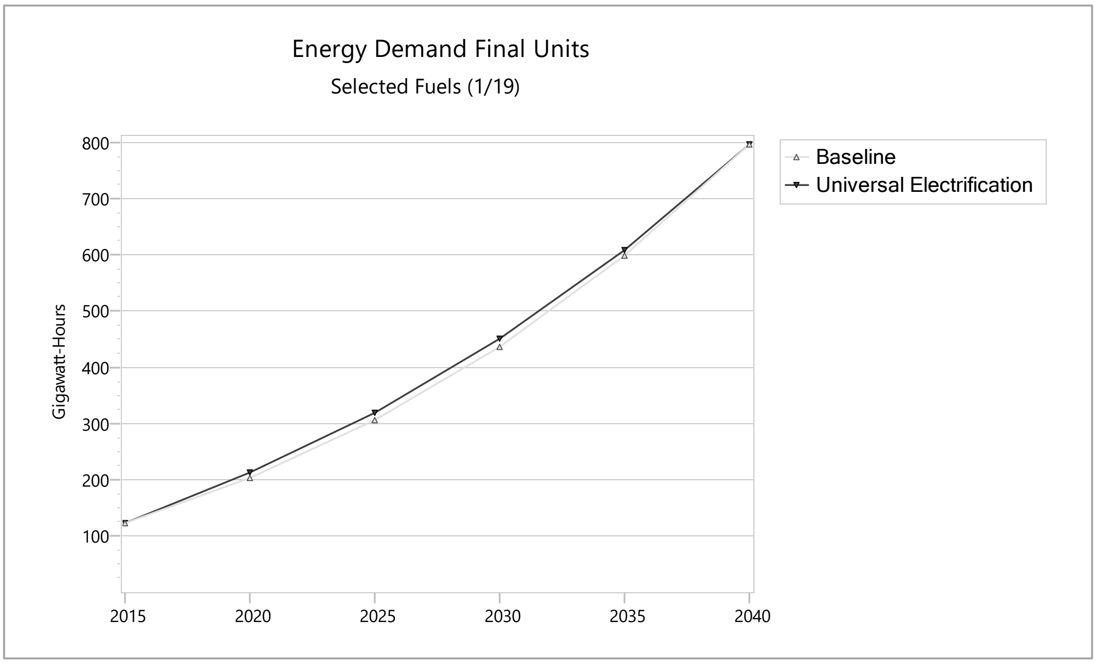


Figure 4.62: Burundian Urban Household's Electricity Demand under U-E

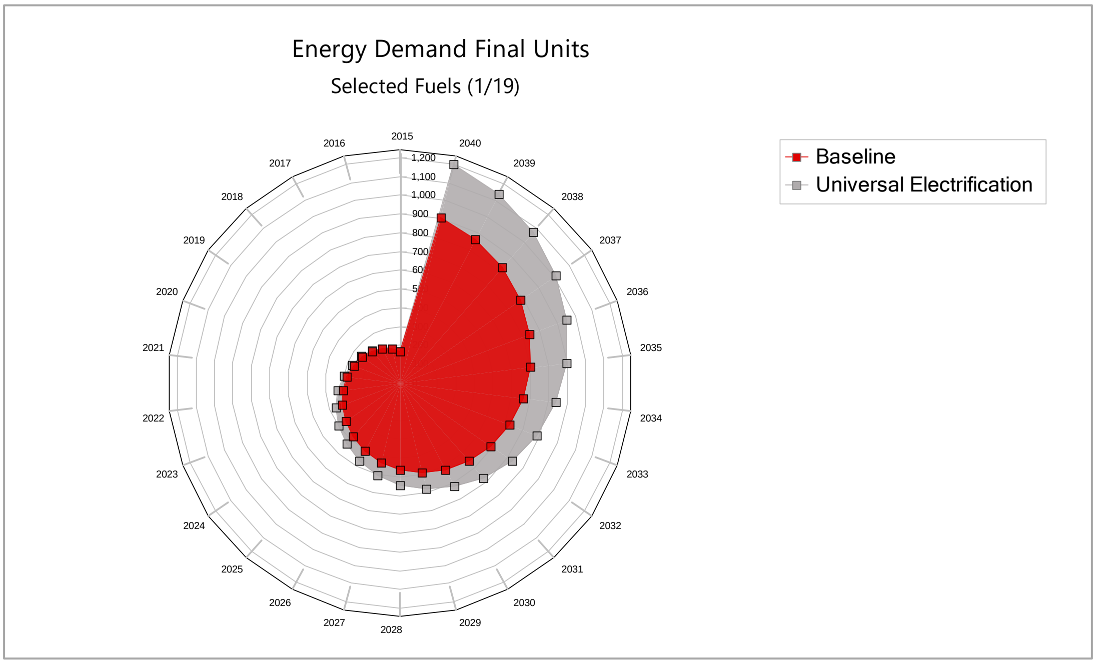


Figure 4.63: Burundian Rural Household's Electricity Demand (GWh) under U-E Scenario

In this scenario, electricity demanded by the economic sectors would remain unchanged as compared to the reference scenario. Table 4.16 and Table 4.17 show the per sector electricity demand under the universal electrification for Kenya and Burundi, respectively.

Table 4.16: U-E Scenario: Electricity Demand (GWh) by Sector for Kenya

Branch	2015	2020	2025	2030	2035	2040
Agriculture	-	-	-	-	-	-
Commercial_Service and Other	1,193.1	415.6	272.5	178.6	117.0	76.6
Industry	4,333.9	5,739.0	4,949.4	4,268.5	3,681.2	3,174.8
Rural Households	837.7	1,999.4	2,805.0	3,823.0	4,148.0	4,480.8
Transport	-	-	-	-	-	-
Urban Households	1,317.9	1,934.5	2,490.1	3,022.0	3,665.2	4,415.7
Total	**7,682.6**	**10,088.5**	**10,516.9**	**11,292.1**	**11,611.4**	**12,147.9**

Table 4.17: U-E Scenario: Electricity Demand (GWh) by Sector for Burundi

Branch	2015	2020	2025	2030	2035	2040
Agriculture	-	-	-	-	-	-
Commercial_Service and Other	60.4	57.2	61.0	64.5	67.4	69.6
Industry	25.3	25.2	45.3	81.4	146.0	261.6
Rural Households	48.4	62.1	116.4	173.2	288.5	405.4
Transport	-	-	-	-	-	-
Urban Households	46.2	95.9	152.5	226.3	313.5	420.3
Total	**180.4**	**240.4**	**375.2**	**545.3**	**815.4**	**1,156.9**

In the both countries, the residential sector would become the main electricity consumer under this policy as the consumption by economic sectors was remained unchanged, hence similar to the reference scenario. Figure 4.64 and Figure 4.65 show the percentage share of electricity demand per sector for Kenya and Burundi respectively.

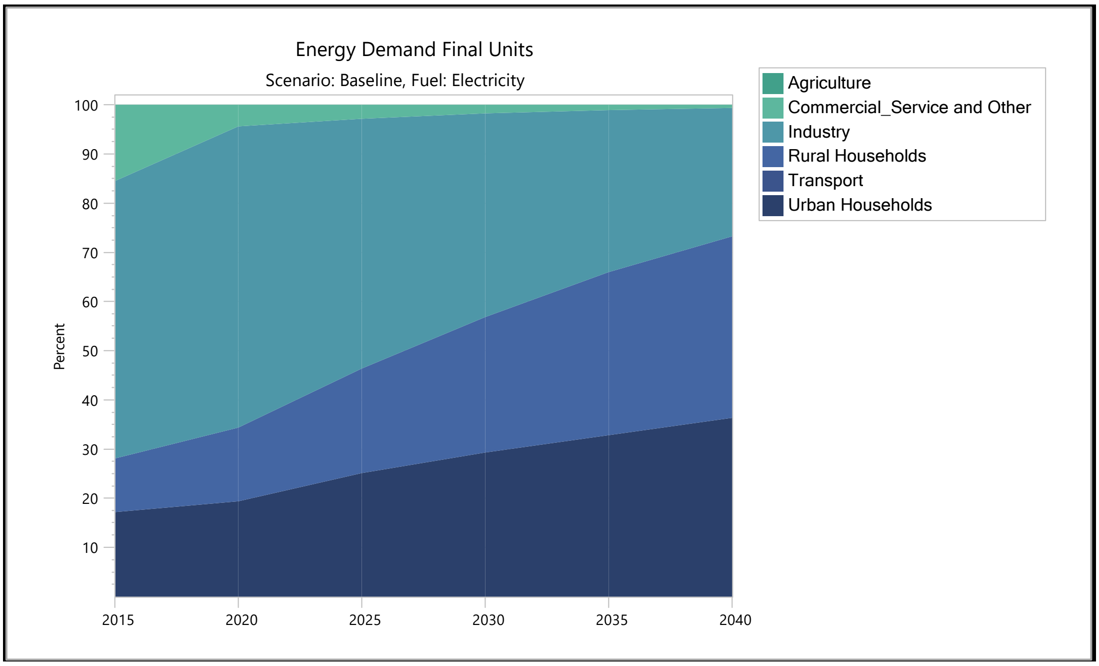


Figure 4.64: Percentage Share of Kenyan Electricity Demand per Sector

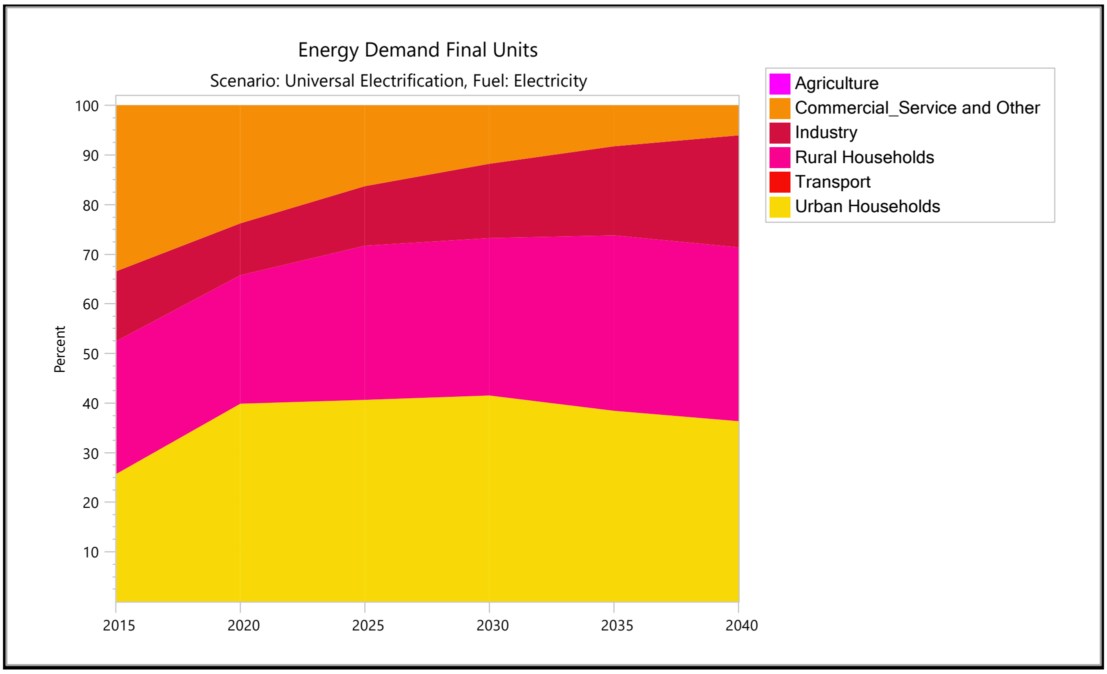


Figure 4.65: Percentage Share of Burundian Electricity Demand per Sector

Therefore, as the U-E Scenario will result in demanding a high amount of electricity to be generated as compared to the baseline scenario, this would cause the increase of GHG emissions. These emissions were determined at 100 – Year (At the point of emissions) in CO_2 Equivalent.

For the case of Burundi, it was expected that the U-E scenario would cause 62.7 tmt CO_2 Equivalent, 142.6 tmt CO_2 Equivalent and 332.2 CO_2 Equivalent in 2020, 2030 and 2040 respectively while these emissions are 62.0 tmt CO_2 Equivalent, 116.9 tmt CO_2 Equivalent and 249.2 tmt CO_2 Equivalent in 2020, 2030 and 2040 respectively in baseline scenario. Figure 4.66 shows the evolution of the GHG emissions for the Burundian electricity generation in the two scenarios.

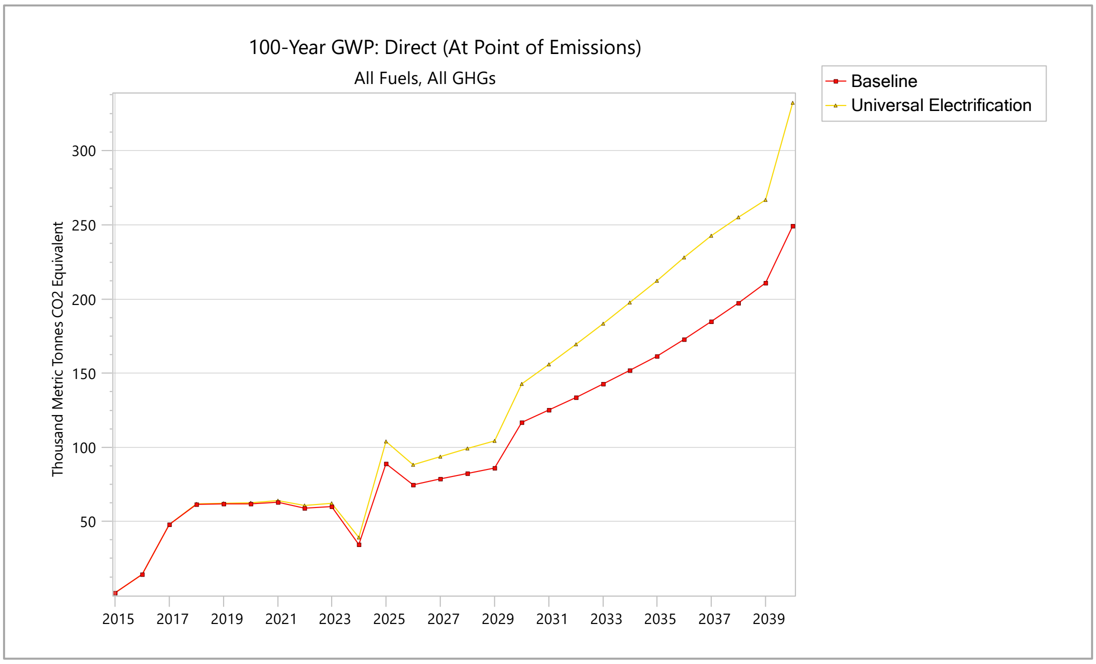


Figure 4.66: GHG Emissions for Burundian Electricity Generation by U-E Scenario

For the case of Kenya, about 566.9 tmt CO_2 Equivalent and 1,658.5 tmt CO_2 Equivalent in 2020 and 2030 respectively are expected to be emitted under this policy while the emissions are 501.6 tmt CO_2 Equivalent and 1,514.2 tmt CO_2 Equivalent in 2020 and 2030 respectively in baseline scenario. Figure 4.67 shows the evolution of the GHG emissions for the Kenyan electricity generation in the two scenarios.

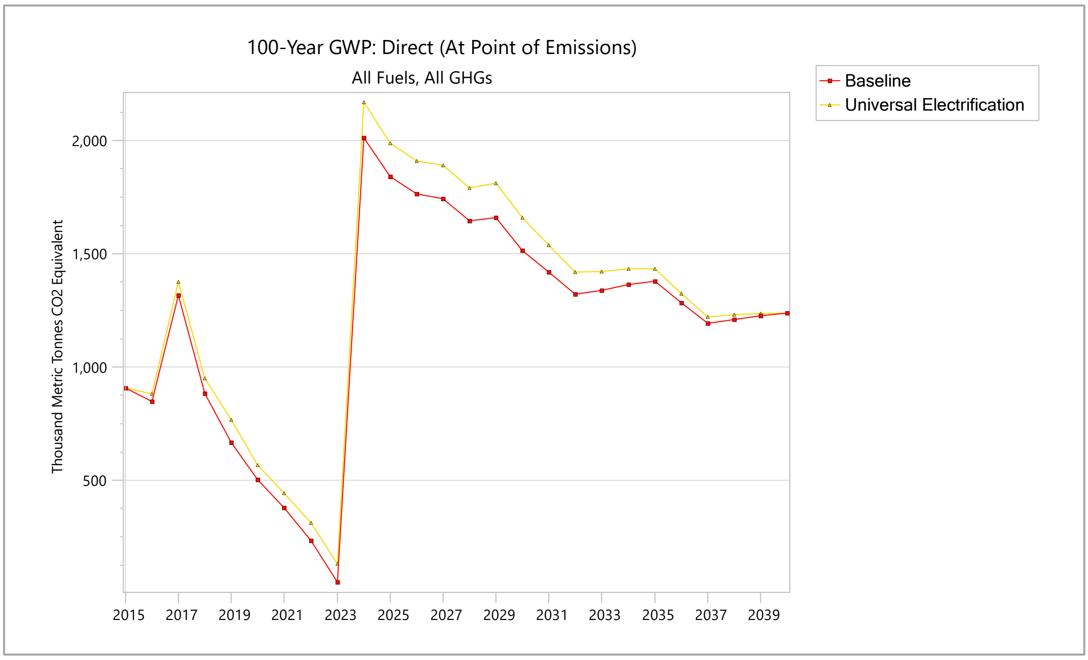


Figure 4.67: GHG Emissions for Kenyan Electricity Generation by U-E Scenario

4.3.4 Climate Smart Scenario: Low-Emissions (LE)

This scenario intended to examine the effect of phasing out all fossil fuelled power plants in electric power systems of the two countries after the year 2030. All the oil fuelled power plants (existing and new) and peat fuelled power plant were considered to be phased out after the year 2030 for Burundi. Similarly, all the oil fuelled power plants (existing and new), coal fired power plants and natural gas fuelled power plant were considered to be phased out after the year 2030 for Kenya.

Therefore, the adoption of this policy will have an effect the GHG emissions reduction and reduction of total electricity generation after the year 2030, as compared to the reference scenario. With this scenario, the low emissions will be emitted by the bagasse power plants in the both countries. After 2030, it is expected that the bagasse fuelled power plants would emit between 1.0 and 1.2 tmt CO_2 Equivalent of GHG emissions in Kenya while the low emissions caused by the biomass fuelled power plants would be between 1.0 and 2.3 tmt CO_2 Equivalent of GHG emissions in Burundi after 2030.

Figure 4.68 and Figure 4.69 show the effect of GHG emissions on the electric power systems of Kenya and Burundi, respectively.

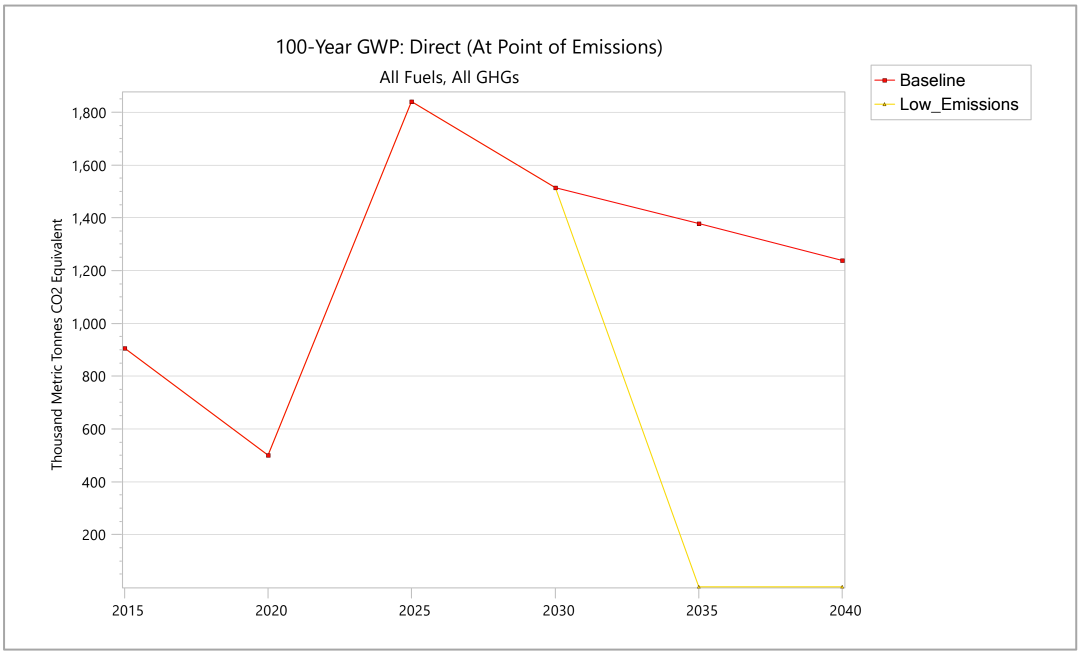


Figure 4.68: GHG Emissions for Kenyan Electricity Generation by L-E Scenario

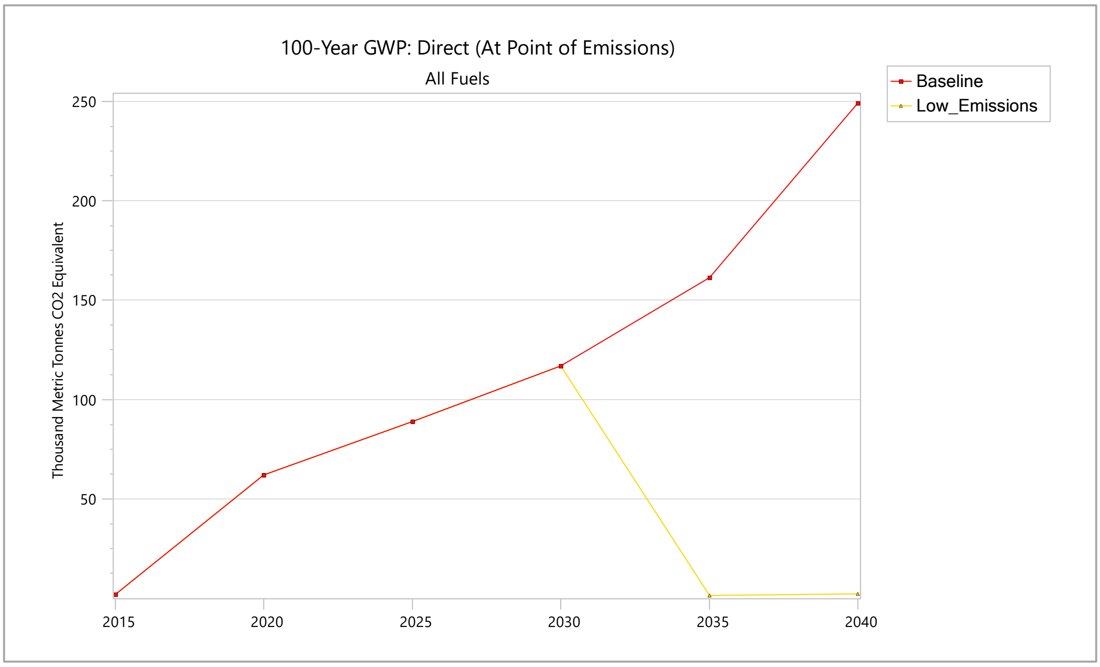


Figure 4.69: GHG Emissions for Burundian Electricity Generation by L-E Scenario

However, the implementation of this policy without additional RE power plants projects implementation other than planned by the Burundian government would lead to the need of importing electricity as compared to reference scenario. For the case of

Kenya, the phasing out of all the fossil fueled power plants would not influence the electricity importation. Table 4.18 and Table 4.19 show the electricity balance with this policy for Burundi and Kenya, respectively.

Table 4.18: L-E Scenario: Burundian Electricity Balance (GWh)

Year	L-E Scenario				BAU Scenario			
	Generation	Imports	T&D L	Tot demand	Generation	Imports	T&D L	Tot demand
2030	511.5	-	-64.5	447.1	511.5	-	-64.5	447.1
2032	585.2	-	-72.6	512.6	585.2	-	-72.6	512.6
2034	664.3	0.5	-81.2	583.6	664.8	-	-81.2	583.6
2036	737.7	18.6	-91.0	665.4	756.3	-	-91.0	665.4
2038	805.1	58.6	-102.3	761.5	863.8	-	-102.3	761.5
2040	973.6	8.4	-114.4	867.6	982.1	-	-114.4	867.6

T&D L: Transmission and Distribution Losses

Table 4.19: L-E Scenario: Kenyan Electricity Balance (GWh)

Year	L-E Scenario				BAU Scenario			
	Generation	Imports	T&D L	Tot demand	Generation	Imports	T&D L	Tot demand
2030	12,332.0	-	-2,022.5	10,309.6	12,332.0	-	-2,022.5	10,309.6
2032	12,741.5	-	-2,028.5	10,713.1	12,741.5	-	-2,028.5	10,713.1
2034	13,052.6	-	-2,015.3	11,037.2	13,052.6	-	-2,015.3	11,037.2
2036	13,396.0	-	-2,004.0	11,391.9	13,396.0	-	-2,004.0	11,391.9
2038	13,806.3	-	-1,999.2	11,807.2	13,806.3	-	-1,999.2	11,807.2
2040	14,125.4	-	-1,977.6	12,147.9	14,125.4	-	-1,977.6	12,147.9

T&D L: Transmission and Distribution Losses

4.3.5 Demand Side Management Policy

In this policy, two policies in demand side management were combined due to their high probability to be implemented at same time.

Therefore, the combination Efficient Lighting (EL) + Efficient Cooking Stoves (EFCS) targets the Demand Side Management by reducing the energy consumed by the residential sector. By implementation of this policy, it would enable to save up to 21,431.6 TJ, 97,047.1 TJ and 102,327.9 TJ in 2020, 2030 and 2040, respectively in Burundi. In Kenya, the implementation of this policy would enable to save up to

36,541.0 TJ, 99,949.1 TJ and 198,839.5 TJ in 2020, 2030 and 2040, respectively. This is shown by Figure 4.70 for Burundi and Figure 4.71 for Kenya.

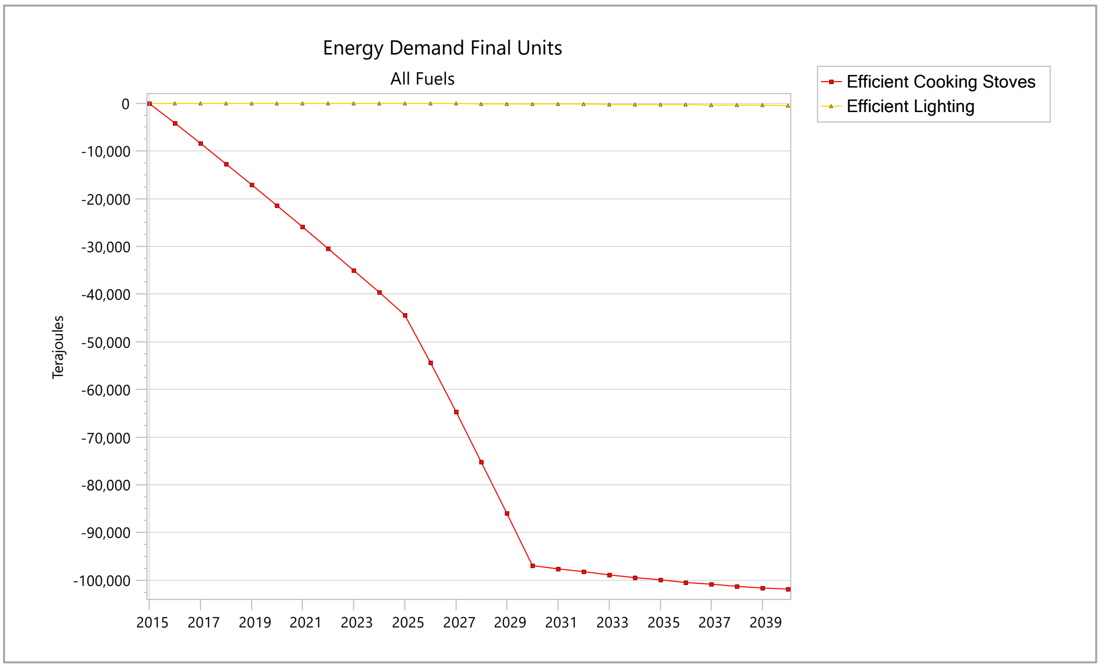


Figure 4.70: Energy Savings in Burundi by the Policy: E-L + EFCS

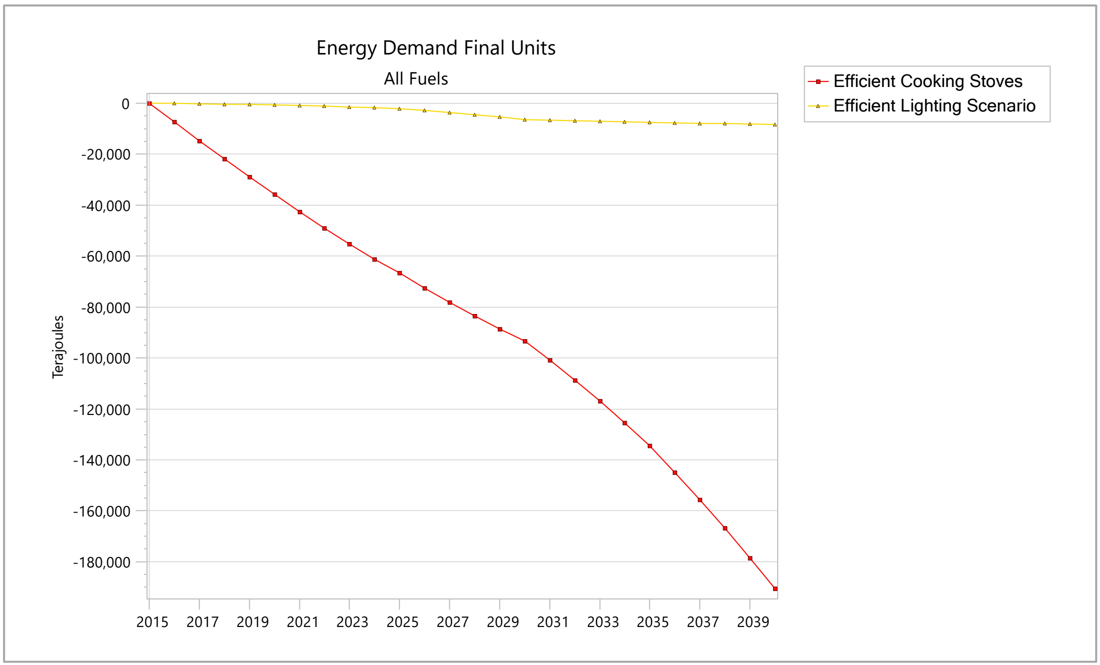


Figure 4.71: Energy Savings in Kenya by the Policy: E-L + EFCS

4.4 Energy Model Validation

4.4.1 Energy Demand Model Validation

In order to validate the simulated model, real data (data between 2015 and 2000) were used to examine to what extent simulated results cohere with real data. Hence, errors resulting in difference of the two were calculated. A similar validation method was also adopted when modelling the energy system of Romania (Gota et al., 2011). Equally, Alam et al. compared simulated results and real data and validated their model with less than 15 % of difference (Alam et al., 1999).

Therefore, available real historical data were used in this case. For the Kenyan case, due to lack of real historical data for charcoal and wood, their associated errors were not calculated. In addition, the Kenyan fuel wood consumptions reported in this study concern the residential sector. Table 4.20, Table 4.21, Table 4.22, Table 4.23 and Table 4.24 show the countries simulated results and their associated errors.

According to the results, the Kenyan forecasting model presents an error between - 8.7 % and 1 % in forecasted oil products demand, less than 3.1 % in forecasted electricity demand, between - 4.3 % and 3.1 % in forecasted coal fuel demand and between - 9.6 % and 2.5 % in forecasted total energy demand.

For the case Burundi, the forecasting model presents an error between - 15.6 % and 22.5 % in forecasted oil products demand, between - 1.7 % and 7.6 % in forecasted electricity demand, between - 1.4 % and 2.4 % in forecasted firewood fuel demand, between - 2 % and 2.3 % in forecasted charcoal energy demand and less than 63 % in forecasted peat demand. In most of the case, the data for the year 2020 was uncertain, and hence this was not considered in the validation.

In most of the cases, the data for the year 2020 was uncertain, and hence this was not considered in the validation. Where real data were not available, the validation was left unchecked.

Table 4.20: Model Validation: Oil Products Demand – Historical Consumption

Year	Burundi (TOE)			Kenya (TJ)		
	Real*	LEAP	Error (%)	Real**	LEAP	Error (%)
2015	115571	148985.1	22.428 %	162419	163,976.9	0.950 %
2016	128407	165053.9	22.203 %	173980	165,755.6	- 4.962 %
2017	164510.1	178066.0	7.613 %	176380	166,892.2	- 5.685 %
2018	209892.4	185839.4	- 12.943 %	181724	167,278.0	- 8.636 %
2019	214290.8	185443.1	- 15.556 %	181270	166,797.9	- 8.676 %
2020	–	172992.0	–	–	165,327.7	–

Source: * for Burundi (BRB, 2020) and **Kenya (IEA, 2022e)

Table 4.21: Model Validation: Electricity Demand – Historical Consumption

Year	Burundi (MWh)			Kenya (GWh)		
	Real*	LEAP	Error (%)	Real	LEAP	Error (%)
2015	183313	180429.9	- 1.6 %	7655	7682.6	0.4 %
2016	208308	192335	- 8.30 %	7912	8022.8	1.38 %
2017	188359	203710.6	7.54 %	8272	8363.7	1.10 %
2018	217258	214203.2	- 1.43 %	8459	8703.9	2.81 %
2019	–	223376.9	–	8769	9041.8	3.02 %
2020	–	230698.4	–	–	9375.4	–

Source: *REGIDESO (REGIDESO, 2022) for Burundi and ** KPLC (The Kenya Power and Lighting Company, 2019) for Kenya
Note: This energy demand refers to total electricity sold by the power companies in these countries, imports excluded

The total charcoal consumed in Burundi between the years 2015 and 2019 was obtained from (Niyongabo et al., 2022) and converted to TJ (charcoal calorific value: 31 GJ/ton) while the total firewood consumed between the years 2015 and 2017 was obtained from (ISTEEBU, 2019) and converted to TJ (firewood calorific value: 15 GJ/ton).

Table 4.22: Model Validation: Wood and Charcoal Fuels Energy Demand in TJ

Year	Burundi						Kenya					
	Wood			Charcoal			Wood			Charcoal		
	Real*	LEAP	E (%)	Real	LEAP	E (%)	Real	LEAP	E (%)	Real	LEAP	E (%)
2015	152434.5	156142.8	2.375 %	14966.86	14680.5	- 1.951 %	–	443,009.4	–	–	29,852.2	–
2016	156092.9	156965.2	0.556 %	18643.77	16314.6	- 14.277 %	–	448,154.2	–	–	30,228.5	–
2017	159839.2	157785.9	- 1.301 %	19569.37	18024.5	- 8.571 %	–	453,112.4	–	–	30,678.1	–
2018	–	158610.0	–	20376.42	19813.1	- 2.843 %	–	457,861.0	–	–	31,208.7	–
2019	–	159443.9	–	21114.96	21591.5	2.21 %	–	462,375.7	–	–	31,827.7	–
2020	–	160295.2	–	–	23437.5	–	–	466,630.5	–	–	32,542.7	–

Source: for Burundi (ISTEEBU, 2019)

The real amount of peat energy consumed in Burundi for the period of 2015 – 2018 (ISTEEBU, 2019) was used to validate the modelled peat energy demand while the real amount of coal consumed from 2015 to 2019 in Kenya (IEA, 2022a) was used for the validation of the results from the developed LEAP model.

Table 4.23: Model Validation: Peat (Burundi) and Coal (Kenya) Fuels Energy Demand – Historical Consumption (in TJ)

Year	Burundi			Kenya		
	Real	LEAP	Error (%)	Real	LEAP	Error
2015	58.3149	155.0	62.377 %	20717	20717.1	0.000 %
2016	140.2527	185.5	24.392 %	20408	19740.8	- 3.380 %
2017	205.0356	218.4	6.119 %	19372	18590.4	- 4.204 %
2018	173.4747	253.9	31.676 %	17737	17249.6	- 2.826 %
2019	–	292.4	–	15222	15700.7	3.049 %
2020	–	467.4	–	–	13924.8	–

Source: for Burundi (ISTEEBU, 2019) and Kenya (IEA, 2022a)

There was high fluctuation of trend in the Burundian peat exploitation causing an important error in validating the model. This may be due to the fact that its use for cooking purpose was found difficult due to its unpleasant smell for cooking and harmful fumes from combustion (Ministry of Energy and Mining, 2011). Hence, the main consumers of this fuel) are communities such as prisons, barracks, boarding schools and hospitals (Ministry of Energy and Mining, 2011).

Table 4.24: Model Validation: Total Final Energy Demand – Historical Consumption

Year	Burundi			Kenya		
	Real	LEAP (TJ)	Error	Real (TJ)	LEAP (TJ)	Error
2015	–	178,933.9	–	667,946	685,331.5	2.5 %
2016	–	182,209.2	–	691,669	693,017.3	0.19 %
2017	–	185,432.3	–	704,593	699,764.2	- 0.69 %
2018	–	188,518.9	–	713,965	705,431.4	- 1.21 %
2019	–	191,262.3	–	777,934	709,863.8	- 9.59 %
2020	–	193,696.4	–	–	712,890.0	–

Source: for Kenya (IEA, 2022f)

4.4.2 Model Validation of the Energy Generation

The energy supply model was validated by comparing modelled generation results by LEAP and real data for the different processes for the base year.

The electricity supplied in the base year was validated using official data obtained from (EAC, 2021b) for Burundi and (The Kenya Power and Lighting Company, 2019) for Kenya. Table 4.25 shows calculated errors resulted by comparing the official data and data from the simulated model in the base year.

Table 4.25: Model Validation: Electricity Supply in GWh (Base year2015)

Plant Type	Burundi			Kenya		
	Real	LEAP	Error (%)	Real	LEAP	Error (%)
Hydro	134	134	0.0 %	3310.1	3310.1	0.0 %
Geo	–	–	–	4,059	4,059	0.0 %
Thermal	3	3	0.0 %	1777.9	1777.9	0.0 %
Solar	–	–	–	0.9	0.9	0.0 %
Wind	–	–	–	37.7	37.7	0.0 %
Bagasse	–	–	–	14	14	0.0 %

It was observed that there was a high correlation between the modelled data and official data for the different power plants in the two countries.

Hence, in order to ensure the accuracy of this model, official data for the years 2016 – 2020 were compared with the results generated by the modelling. The official data for Kenya was taken from (IEA, 2022b) and from (EAC, 2021b) for the case of Burundi. Table 4.26 and Table 4.27 show errors resulting from comparing the two type of data for Burundi and Kenya, respectively.

From the results, the Burundian forecasting energy supply model presents an error between - 2.8 % and 6 % in forecasted hydropower generation and an error between - 0.42 % and 5.63 % in forecasted thermal power supply.

For the case Kenya, the forecasting model presents an error between - 13.8 % and 13.2 % in forecasted hydropower plants generation, an error between - 10.6 % and 11.65 % in forecasted thermal power plants generation, an error between - 9.8 % and 5.56 % in forecasted solar PV plants generation, an error between - 11.08 % and 9.31 % in forecasted geothermal power plants generation, an error between - 12.42 % and 2.50 % in forecasted bagasse power plants generation and an error between - 8.23 % and 19.11 % in forecasted wind power plants generation.

Table 4.26: Model Validation: Burundian Electricity Supply in GWh

Year	Hydropower			Thermal		
	Official	LEAP	Error (%)	Official	LEAP	Error (%)
2016	143	142.7	- 0.21 %	24	23.9	- 0.42 %
2017	99.8	106	5.85 %	73.8	80.4	8.21 %
2018	133.2	129.6	- 2.78 %	99	104.9	5.62 %
2019	–	130.3	–	–	105.4	–
2020	–	130.8	–	–	105.9	–

Table 4.27: Model Validation: Kenyan Electricity Supply in GWh

Techno	2016			2017			2018			2019			2020		
	Off.	LEAP	E %	Off.	LEAP	E %	Off.	LEAP	E %	Off.	LEAP	E %	Off.	LEAP	E %
Hydro	3960	3784	- 4.65 %	2777	2819.3	1.50 %	3986	3916.7	- 1.77 %	3205	3690.4	13.15 %	4233	3720.4	- 13.78 %
Therm.	1470	1497	1.80 %	2534	2292.6	- 10.53 %	1446	1534.2	5.75 %	1313	1320.6	0.58 %	754	853.4	11.65 %
PV	60	60	0.00 %	73	77.3	5.56 %	90	89.1	- 1.01 %	92	83.8	-9.79 %	88	83.9	- 4.89 %
Geo	4484	4365.4	- 2.72 %	4756	4764.9	0.19 %	5128	4616.5	- 11.08 %	5235	5203.3	- 0.61 %	5060	5579.7	9.31 %
Bag	229	203.7	- 12.42 %	157	159.5	1.57 %	169	152.4	-10.89 %	148	151.5	2.31 %	148	151.8	2.50 %
Wind	56	57	1.75 %	61	61.3	0.49 %	375	463.6	19.11 %	1563	1444.1	- 8.23 %	1331	1448.3	8.10 %

Note: Techno: Electric power technology; Bag: Bagasse; Therm.: Thermal power plant, Geo: Geothermal

Table 4.28: Model Validation: Electricity Supply – Total Generation in GWh

Year	Burundi			Kenya		
	Official	LEAP	Error	Official	LEAP	Error
2015	137	137	0.00 %	9279	9736	4.7 %
2016	167	166.6	- 0.24 %	9817	9540	- 2.90 %
2017	173.6	186.4	6.87 %	10204	9758.1	- 4.57 %
2018	232.2	234.5	0.98 %	10703	10396	- 2.95 %
2019	–	235.7	–	11493	11099.9	- 3.54 %
2020	–	236.6	–	–	11173	–

Additionally, the total electricity generation between the years 2016 – 2020 was also validated by determining an error resulted from comparing the official total electricity supply in these years with the LEAP results. The official data were obtained from (The Kenya Power and Lighting Company, 2019) for Kenya and from (EAC, 2021b) for Burundi. The error resulting in the difference between official data and LEAP results is between -0.24 % and 6.87 % for Burundi and between - 4.57 % and 4.7 % for the case of Kenya. Table 4.28 shows the errors resulted by comparing the two type of data.

Furthermore, losses due to power transmission and distribution were analyzed by comparing the modelling results and real data. The official data were obtained from (The Kenya Power and Lighting Company, 2019) for Kenya and from (REGIDESO, 2022) for Burundi. Table 4.29 shows the calculated errors resulting in the difference of LEAP results and real data for the two countries. The error is between - 8.5 % and 7.7 % for Burundi and between - 1.9 % and 17 % for the case of Kenya.

Table 4.29: Model Validation: Electricity supply System Losses

Year	Burundi (MWh)			Kenya (GWh)		
	Official	LEAP	Error	Official	LEAP	Error
2015	74057	72982.9	- 1.5 %	1624	1849.2	12.2 %
2016	79134	72954.7	- 8.47 %	1905	1869.7	- 1.89 %
2017	70975	76882.5	7.68 %	1932	2223.3	13.10 %
2018	98837	97591.8	- 1.28 %	2244	2703.6	17.00 %
2019	–	94559.6	–	2724	2714.8	- 0.34 %
2020	–	90534.0	–	–	2719.3	–

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMENDATIONS

5.1 Summary

This research applied the MCDM "Multi-Criteria Decision Making" method and the LEAP "Long-range Energy Alternatives Planning" model.

The application of the MCDM method aimed at prioritizing power technology options based on available energy resources in order to solve the dilemma of most sustainable technologies countries energy mix model. Eight technologies were found to be the options in Kenya: Geothermal, Hydropower, Biomass, Wind, Solar PV, CSP, Coal and Oil while seven alternatives were found in Burundi: Hydropower, Solar PV, Biomass, Wind, CSP, Peat and Geothermal. Hence, energy options were evaluated against four sustainable dimensions (Economic, Social, Environmental and Technical). Therefore, 17 sustainable indicators were used after consultation of energy experts. By applying a hybrid AHP - TOPSIS model, results showed that Solar PV is ranked in the first position for the two countries. With different scenarios performed, fossil fuels and Biomass were found to have a fragile sustainability performance; with a massive exploitation of fossil fuels considered in this study (available reserves considered to be totally exploited in the next 20 years), they did not compete with RE technologies. This would give them a low chance for energy market integration in Kenya, especially for investors in energy projects. However, due to intermittency of RE technologies, these fossil fuels would help to maintain the reliability of Kenyan power supply in their energy mix model.

By using LEAP model, current and future energy balance of the countries were examined. The current and future energy demanded by the residential and economic sectors of Burundi and Kenya were investigated. All end-use fuels were analyzed and forecasted up to year 2040. The current and future energy demand was built as baseline scenario where historical trends of population, economic characteristics, rate of electrification and urbanization, and energy consumption (energy intensity) were used as key data to perform this demand. The results showed that the total energy demand of the countries will keep rising and this will influence an increase of GHG emissions. This was 178,993.9 TJ in 2015 and is projected to grow up to 417,980.0 TJ in 2040 for Burundi while it was 685,331.5 TJ in 2015 and is expected to grow up to 857,518.3 TJ in 2040 for Kenya. On the other hand, the increase in energy demand is expected to cause the increase in GHG emissions. Simulations of direct emissions (at the point of emissions), measured at 100 –Year GWP "Global Warming Potential" show an rise in CO_2 Equivalent emitted as the energy demand increases. In Kenyan residential sector, they were 6,079.9 Thousand Metric Tonnes (tmt) in 2015 and are expected to rise up to 6,503.7 tmt, 7,375.3 tmt and 8,661.0 tmt by 2020, 2030 and 2040 respectively. Only firewood constituted 73.3 % of the total GHG emissions by the households in 2015 and is expected to remain with a big share of 64.8% in 2040. For the case of Burundi residential sector, 1,753.9 tmt CO_2 Equivalent were emitted in 2015 and it is expected that up to 1,859.7 tmt CO_2 Equivalent, 2,095.7 tmt CO_2 Equivalent and 2,358.7 tmt CO_2 Equivalent will be emitted by 2020, 2030 and 2040 respectively. Despite its predicted decline in GHG emissions share, the firewood contributed to 87.8 % of the emissions in 2015 and it is expected to remain the main contributor of GHG emissions by 2040 with a share of 59.6 %. The residential sector will remain the main consumer of final energy demand in these countries as its consumption is expected to constitute 79.6 % and 53.5 % of total energy demand by 2040 for Kenya and Burundi, respectively.

Alternative energy policies were also analyzed for the countries. At demand side management, two alternative energy policies “adoption of efficient lighting and efficient cooking stoves” and two policies on supply side “climate smart - low emissions and universal electrification” were modelled as they were found to be strategic priorities by the countries Governments as highlighted by several countries’ published energy reports. The alternative energy policies were built based on baseline scenario. The baseline scenario was the reference for performing the analysis of the different policies. The efficient lighting policy would enable these countries to save up to 203.3 GWh, 1,806.3 GWh and 2,300.9 GWh by 2020, 2030 and 2040 for Kenya respectively and up to 2.5 GWh, 40.5 GWh and 124.6 GWh by 2020, 2030 and 2040 for Burundi, respectively while the implementation of efficient cooking stoves policy is expected to save up 35,809.3 TJ, 93,446.3 TJ and 190,556.4 TJ by 2020, 2030 and 2040 respectively for Kenya and up to 21,422.7 TJ, 96,901.2 TJ and 101,879.2 TJ by 2020, 2030 and 2040 for Burundi, respectively. In addition, by implementing the efficient cooking stoves policy, 1,787.5 Thousand Metric Tonnes CO_2 Equivalent would be avoided in comparison to the reference scenario by 2040 for Kenya and up to 903.4 tmt CO_2 equivalent for the case of Burundi. Under universal electrification policy, the households demand for electricity is expected to be 3,933.9 GWh and 6,845.0 GWh by 2020 and 2030 respectively for Kenya against 3,220.8 GWh and 5,862.5 GWh by 2020 and 2030 respectively under the baseline scenario. Similarly, electricity demanded by the Burundian residential sector is expected to grow up to 158.0 GWh, 399.4 GWh and 825.7 GWh by 2020, 2030 and 2040 while the expectations were 148.3 GWh, 301.2 GWh and 536.5 GWh by 2020, 2030 and 2040 respectively under the reference scenario. This demand would be 982.5 GWh and 98.2 GWh higher than the reference scenario by 2030 for Kenya and Burundi, respectively.

Lastly, the simulated model was validated. To validate the simulated model, real data between the years 2015 and 2000 were used to inspect to what extent simulated results cohere with real data. Errors resulting in difference of the two were calculated. The error was between - 8.7 % and 1 % in forecasted oil products demand, less than 3.1 % in forecasted electricity demand, between - 4.3 % and 3.1 % in forecasted coal fuel demand and between - 9.6 % and 2.5% in forecasted total energy demand for Kenya. For the case Burundi, the error was between - 15.6 % and 22.5 % in forecasted oil products demand, between - 1.7 % and 7.6 % in forecasted electricity demand, between - 1.4 % and 2.4 % in forecasted firewood fuel demand, between - 2 % and 2.3 % in forecasted charcoal energy demand and less than 63 % in forecasted peat demand. For the generation side, error was between - 2.8 % and 6 % in forecasted hydropower generation and between - 0.42 % and 5.63 % in forecasted thermal power supply for Burundi. For the case of Kenya, the error was between - 13.8 % and 13.2 % in forecasted hydropower plants generation, between - 10.6 % and 11.65 % in forecasted thermal power plants generation, between - 9.8 % and 5.56 % in forecasted solar PV plants generation, between - 11.08 % and 9.31 % in forecasted geothermal power plants generation, between - 12.42 % and 2.50 % in forecasted bagasse power plants generation and between - 8.23 % and 19.11 % in forecasted wind power plants generation.

5.2 Conclusions

This study resulted into four main conclusions. First, based on the findings, RE (especially Solar PV, Wind and CSP), Biomass excluded, always occupy first positions in most all scenarios. With a massive exploitation of fossil fuels considered in this study (available reserves were considered to be totally exploited in the next 20 years), they are not found to compete with RE (especially Solar PV, Wind and CSP) in all the scenarios, except in economic scenario where CSP occupies the last position. Therefore, it is logical to conclude that the high deployment of RE technologies in the countries will not harm their economic growth.

Secondly, the total energy demand of the countries will keep rising and households are expected to remain the main consumer of total final energy. On the other hand, the increase in energy demand is expected to cause the increase in GHG emissions. The main fuels consumed in the residential sectors of the countries being biomass (wood and charcoal) for cooking, it is clear that a high deforestation rate is expected if any policy is implemented.

Thirdly, from the findings of analyzed policies found to be key priorities for implementation by the countries Governments, it is reasonable to conclude that: while universal electrification will require the countries to increase their power supply, the implementation of energy efficiency and conservation policies for highly consumed fuels will enable to save a significant amount of energy, reduce the rate of deforestation and mitigate GHG emissions. Low-emission scenario by phasing out all fossil-fired power plants after 2030 is expected to cause Burundi import a significant amount of electricity while this policy can be implemented in Kenya without the need to import.

Lastly, the error of the developed model helps to conclude the consistency of forecasted fuels, apart from some major discrepancies such as Peat fuels for some years.

5.3 Recommendations

5.3.1 Policy Recommendations

The energy situation in the region was expected to deteriorate if planning for a sustainable development is not actualized. The application of the presented approach would offer an effective, efficient and systematic energy planning for decision support framework; this would help policy planners in the evaluation of priority energy resources that the governments should invest in. The results from this study would help the regions (Kenya and Burundi, deeply analyzed) energy policymakers to strategize on all-fuels energy supply in order to meet the forecasted demand. However, this cannot be achieved without strategic supporting mechanisms. Therefore, the following recommendations were suggested as supporting mechanisms:

a) At Technical level:

- It was recommended to the region to target technologies suitable to the countries sustainability context. This would help the countries energy policy-makers, investors as well as energy projects' investors in the countries to have an understanding of sustainable power technologies when planning for future energy projects.
- Multiply RE technologies in their generation system.
- Raise the spirits of regional technology transfer among countries in order to facilitate the energy import-exports "e.g. East Africa Power Pool".
- Renovate their power infrastructure and energy equipment at national level, especially transmission lines.
- Encourage innovative energy systems at national level for efficient lighting and improved cooking stoves.

b) At Regulatory level:

- Establish national agencies for continuous energy efficiency improvement studies, energy data collection and renewable energy integration studies.
- The government should utilize print, electronic and social media to highlight the significance of household energy utilization in order to improve and adopt modern, clean and sustainable energy sources.

c) At Social level:

- The government should strengthen the relationship with local administration to make sure that the government policy targets of incorporating renewable energy in the country are producing the required results. For the proper execution, there should be a two-way flow of information, i.e., government plans and strategies should be deliberated, and stakeholders' input should be attained. These include among (i) adopt integrated household energy policy approaches and improve stakeholder relationship; (ii) raise awareness of the benefits of clean bioenergy cooking options; (iii) enhance research, development, and technical capacity.

d) At Financial level:

- Allocate funds for RE energy projects developers in form of loans, grants, tax credits and tax rebates at national or regional level.
- Allocate funds for research and development. This would help to strengthen a quick implementation of energy policies of the countries. E.g. more efficient cooking stoves than existing would result in lower quantities of wood consumption and lower deforestation rate (efficient cooking stoves policy).

5.3.2 Further Research Recommendations

This study made its assumptions that no more reserves of fossil fuels will be discovered in future. Hence, any additional discovery may change the prioritization of the results found. Furthermore, this study was limited by some data availability and hence, different data sources were relied on in developing the model. Some data availability in local context were an obstacle and data from similar projects conducted in other countries were considered which may differ from local situation. Hence, future research by using local data would give robust results as this would minimize the error of the developed model and improve the accuracy of the forecasted results.

In ranking the power generation technologies of the countries using the MCDM model, the study assumed that power generation is only to be supplied by local power plants. The influence of imports and exports was neglected. This study also recommends future research to incorporate spatial and temporal change of sub-criteria as some indicators (e.g. LCOE) are expected to vary in future.

The LEAP model has the ability to optimize electricity supply and capability for demand-driven and physical accounting modelling (SEI, 2011). Consequently, the required investments affecting the analyzed policies were not modelled as LEAP modeldoes not perform the cost-optimization..

In addition, historical energy from fuel wood consumed by the Kenyan industrial and commercial sectors was neglected due lack of data. Hence, future researches are recommended to examine the annual fuel wood energy demanded by these sectors which would be not negligible.

It is also recommended that the use of ethanol fuels in future should be addressed as it may be one the options to reduce the use of biomass for cooking and lighting as well as reduce the use of diesel fuel in transport sector when transformed into biodiesel in order to mitigate the Greenhouse gas emissions in the region.

The LEAP model does not perform the effect of high penetration of renewable energy technologies on grid stability. Therefore, further analysis is recommended to examine the effect of grid stability in the countries for the climate smart “Low emissions” policy simulated in this study with LEAP.

At last, it is recommended to analyse in detail the energy policies regarding the transport sector which is the main Greenhouse gas emitter in the region caused by a high consumption of petroleum products. For instance, the transport sector is the main consumer of petroleum products in Kenya with a demand of 86 % (72 % for road transport and 14% of air transport) whereas the demand for industrial commercial is only 12 % and 2% for other (Ministry of Energy, 2020). As national policy for energy conservation and reduce pollution, the Kenyan government plans the adoption from the electrical vehicles (E-Mobility) by an annual increase of 5 % for all imported vehicles as of 2025 (Ministry of Energy, 2020). The implementation of this policy is not yet clear in Burundi (Ministry of Energy and Mining, 2013). The adoption of E-Mobility would also reduce a significant amount of CO_2 emissions. However, this policy was not considered in this study due lack of clarity on predicted total number of vehicles to be imported as from 2025 (for Kenya) and lack of reference stating any initiative for implementing this policy for the case of Burundi. Therefore, further research incorporating this policy would improve this work.

5.4 Research Contributions

This research has contributed to the concept of sustainably prioritizing power technology options in the region using sustainable dimensions. This provides a critical policy contribution to the countries governments and energy projects investors by solving the dilemma of technologies prioritization in capacity expansion.

Additionally, this study has provided robust energy planning policies in the countries where all energy fuels demanded by residential and all economic sectors are considered for the development of the region. This provides useful insights to the countries' policymakers.

Most importantly, the model developed in this study provides technical information required by the countries policy makers to trace the countries roadmaps for implementation of energy efficiency and conservation policies for highly consumed fuels.

At last, the results from this research provides useful information for the countries to meet their NDC "Nationally Determined Contributions" to reduce the GHG emissions and the achievement of the SDG – 7.

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APPENDICES

Appendix 1: Descriptive data Analysis

A descriptive statistical analysis of population and GDP was conducted to provide the basic features of the dataset used for Burundi and Kenya. Findings of the descriptive statistics are presented in the following tables:

National Population of Burundi (2000 – 2020)

Column1	
Mean	8825927.238
Standard Error	378234.4352
Median	8675606
Mode	#N/A
Standard Deviation	1733287.93
Sample Variance	3.00429E+12
Kurtosis	-1.15763199
Skewness	0.249278495
Range	5511910
Minimum	6378871
Maximum	11890781
Sum	185344472
Count	21
Confidence Level(95.0%)	788983.2063

National GDP of Burundi (2000 – 2020)

Column1	
Mean	1899920888
Standard Error	176077494.8
Median	2032135247
Mode	#N/A
Standard Deviation	806888448
Sample Variance	6.51069E+17
Kurtosis	-1.636215644
Skewness	-0.1290778
Range	2319740435
Minimum	784654423.6
Maximum	3104394858
Sum	39898338646
Count	21
Confidence Level(95.0%)	367291218

National Population of Kenya (2000 – 2020)

Column1	
Mean	42343518.9
Standard Error	1496583.543
Median	42030684
Mode	#N/A
Standard Deviation	6858207.368
Sample Variance	4.7035E+13
Kurtosis	-1.235985786
Skewness	0.114612382
Range	21806743
Minimum	31964557
Maximum	53771300
Sum	889213897
Count	21
Confidence Level(95.0%)	3121818.566

National GDP of Kenya (2000 – 2020)

Column1	
Mean	48760733389
Standard Error	6572200523
Median	45405587557
Mode	#N/A
Standard Deviation	30117606379
Sample Variance	9.0707E+20
Kurtosis	-1.138602974
Skewness	0.364376458
Range	88308369426
Minimum	12705357103
Maximum	1.01014E+11
Sum	1.02398E+12
Count	21
Confidence Level(95.0%)	13709370059

Appendix 2: Designed Questionnaire for Energy Experts

Subject: A survey - Questionnaire to determine the sustainable energy indicators for energy technologies selection in Kenya/Burundi

Respondent’s Name: ………………………………Date: ……………
Email Address: ……………………………………Tel: ………………
Institution: ……………………………………………

1. Basic Information

1.1. Country of citizenship, please tick as appropriate:

- Kenya
- Burundi
- Other (Please specify): ………..

1.2. ***What is your age?*** **Please tick as appropriate:**

- 18 to 25
- 25 to 35
- 35 to 45
- 45 to 65
- 65+
- Would rather not say

1.3. ***Gender.*** **Please tick as appropriate*:***

- Male
- Female
- Transgender

1.4. ***Job title description.*** **Please tick as appropriate*:***

- Lecturer at University
- Assistant Lecturer
- Field officer
- Electrician
- Administrative authority
- Other. Please specify: ……..

2. Priority among criteria. Please tick as appropriate:

2.1. Among the following 4 sustainable dimension criteria, which one do you find more important for your country in terms of electrification project:

- ○ Economic
- ○ Environmental
- ○ Technical
- ○ Social

2.2. To what extent are the following criteria important for an electrification project in your country to you? (On a scale of 1 to 10, 1 being the lowest)

	1									10
- Economic	○	○	○	○	○	○	○	○	○	○
- Environmental	○	○	○	○	○	○	○	○	○	○
- Technical	○	○	○	○	○	○	○	○	○	○
- Social	○	○	○	○	○	○	○	○	○	○

2.3. From the list below "selected from sustainable energy indicators in literature review", select which ones you find most important for your country:

- ○ Efficiency
- ○ LCOE
- ○ Installed capacity
- ○ Investment cost
- ○ Variable O&M cost
- ○ Fixed O&M cost
- ○ CO_2 emissions
- ○ Reliability
- ○ Water consumption
- ○ Capacity factor
- ○ Technology maturity
- ○ Resource availability
- ○ Ability to respond to peak load
- ○ Land requirement

- ○ NOx emissions
- ○ SO_2 emissions
- ○ CH_4 emissions
- ○ Job creation
- ○ Safety risks
- ○ Social acceptability
- ○ Other (specify)________________

2.4. To what extent are the following technical indicators important for an electrification project in your country to you? (On a scale of 1 to 10, 1 being the lowest). Please tick only the indicators you selected in 2.3.

	1									10
- Efficiency	○	○	○	○	○	○	○	○	○	○
- Project lifetime	○	○	○	○	○	○	○	○	○	○
- Installed capacity	○	○	○	○	○	○	○	○	○	○
- Reliability	○	○	○	○	○	○	○	○	○	○
- Capacity factor	○	○	○	○	○	○	○	○	○	○
- Technology maturity	○	○	○	○	○	○	○	○	○	○
- Resource availability	○	○	○	○	○	○	○	○	○	○
- Ability to respond to peak load	○	○	○	○	○	○	○	○	○	○
- Other (specify)……….	○	○	○	○	○	○	○	○	○	○

2.5. To what extent are the following economic indicators important for an electrification project in your country to you? (On a scale of 1 to 10, 1 being the lowest). Please tick only the indicators you selected in 2.3.

	1									10
- LCOE	○	○	○	○	○	○	○	○	○	○
- Investment cost	○	○	○	○	○	○	○	○	○	○
- Variable O&M cost	○	○	○	○	○	○	○	○	○	○
- Fixed O&M cost	○	○	○	○	○	○	○	○	○	○
- Other (specify)………..	○	○	○	○	○	○	○	○	○	○

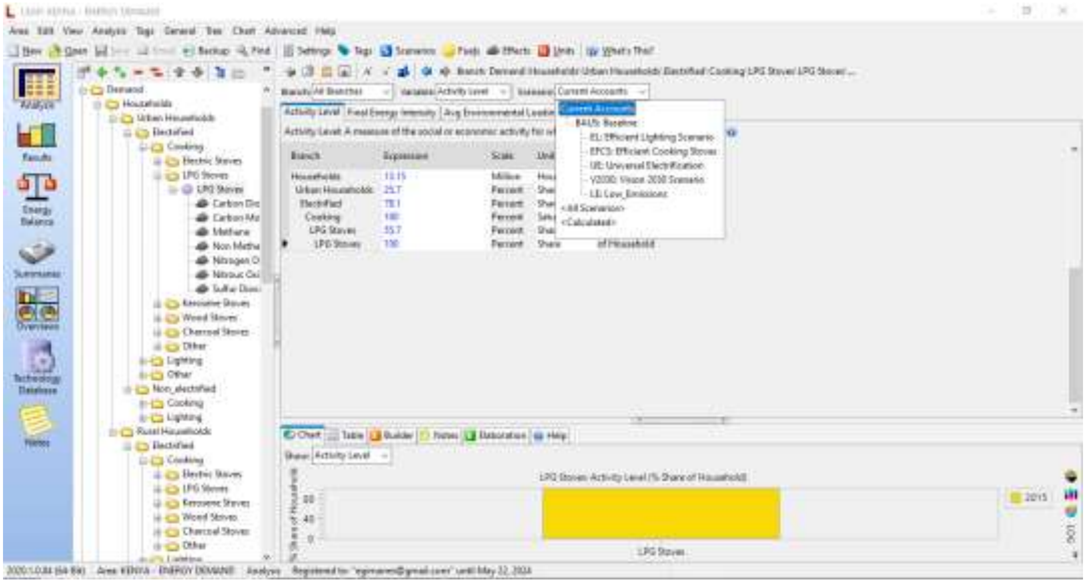
2.6. To what extent are the following environmental indicators important for an electrification project in your country to you? (On a scale of 1 to 10, 1 being the lowest). Please tick only the indicators you selected in 2.3.

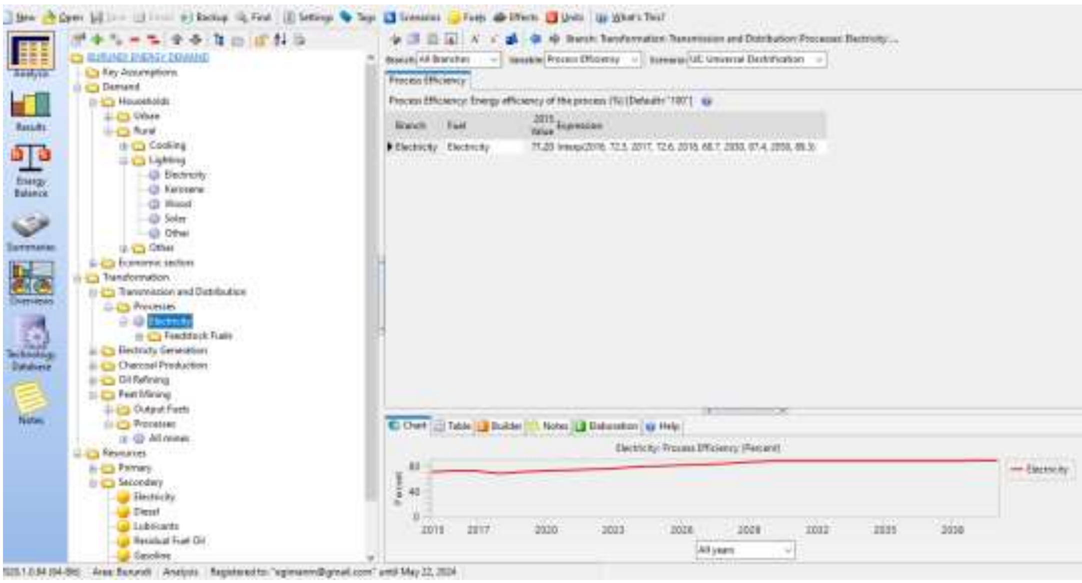
	1									10
- CO_2 emissions	○	○	○	○	○	○	○	○	○	○
- Land requirement	○	○	○	○	○	○	○	○	○	○
- NOx emissions	○	○	○	○	○	○	○	○	○	○
- Water consumption	○	○	○	○	○	○	○	○	○	○
- SO_2 emissions	○	○	○	○	○	○	○	○	○	○
- CH_4 emissions	○	○	○	○	○	○	○	○	○	○
- Other (specify)………..	○	○	○	○	○	○	○	○	○	○

2.7. To what extent are the following social indicators important for an electrification project in your country to you? (On a scale of 1 to 10, 1 being the lowest). Please tick only the indicators you selected in 2.3.

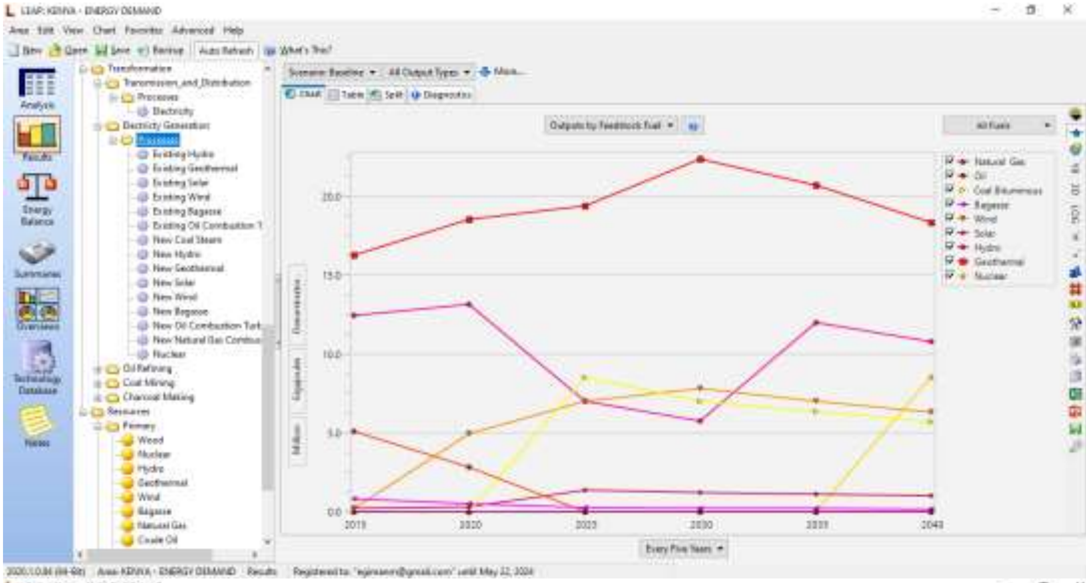
	1									10
- Job creation	○	○	○	○	○	○	○	○	○	○
- Safety risks	○	○	○	○	○	○	○	○	○	○
- Social acceptability	○	○	○	○	○	○	○	○	○	○
- Other (specify)…………..	○	○	○	○	○	○	○	○	○	○

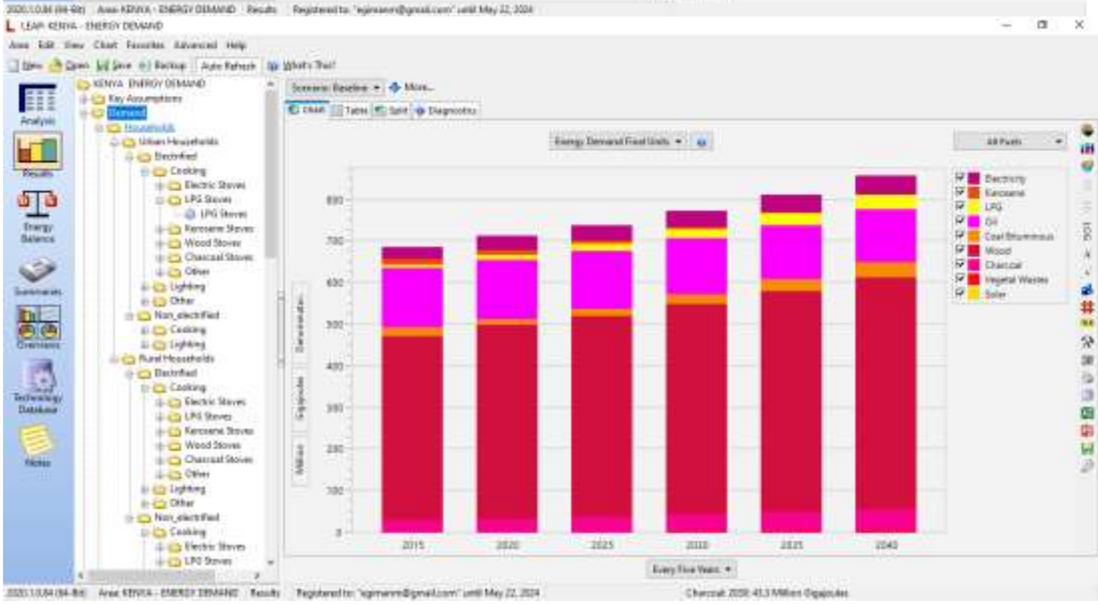
Appendix 3: Some Screenshots for LEAP Analysis

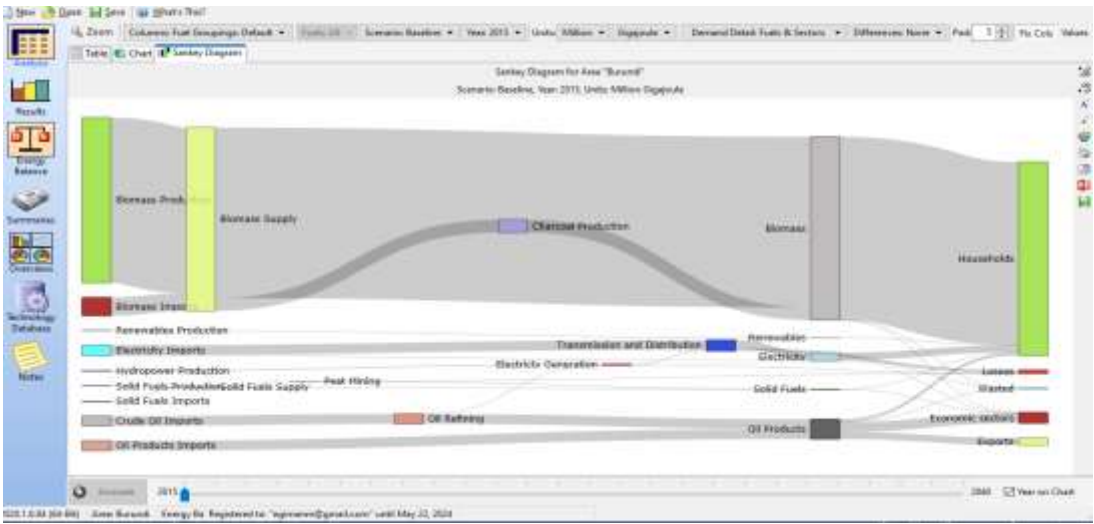




Appendix 4: Some Screenshot for LEAP Simulations







Appendix 5: Historical Population Data for Burundi and Kenya (The World Bank, 2022)

Year	Burundi		Kenya	
	Population	Urban-population	Population	Urban population
2000	6378871	526002	31964557	6358390
2001	6525546	552126	32848569	6648222
2002	6704118	582052	33751746	6949822
2003	6909161	615468	34678781	7264511
2004	7131688	651765	35635267	7593875
2005	7364857	690455	36624897	7938446
2006	7607850	731647	37649039	8299731
2007	7862226	775530	38705934	8677870
2008	8126104	822199	39791984	9072572
2009	8397661	871341	40901798	9482264
2010	8675606	923258	42030684	9907053
2011	8958406	977810	43178270	10349400
2012	9245992	1034996	44343469	10809164
2013	9540302	1095417	45519986	11286225
2014	9844301	1159265	46700063	11778223
2015	10160034	1227129	47878339	12284624
2016	10488002	1299254	49051531	-
2017	10827010	1375680	50221146	13339741
2018	11175379	1456375	51392570	13891412
2019	11530577	1541177	52573967	14461521
2020	11890781	1629988	53771300	15053275

Appendix 6: Historical GDP Data for Burundi and Kenya (The World Bank, 2022)

Year	Burundi				Kenya			
	National GDP		GDP/Capita		National GDP		GDP/Capita	
	(USD)	% growth	(USD)	% growth	(USD)	% growth	(USD)	% growth
2000	870486065.88	- 0.856864058	136.4639708	- 2.593559293	12705357103.01	0.599695392	397.4826588	- 2.125154281
2001	876794723.07	2.055807108	134.3634269	- 0.238106	12986007425.88	3.779906496	395.3294716	0.987009104
2002	825394490.16	4.446519412	123.1175361	1.664464582	13147743910.72	0.54685953	389.5426302	- 2.143715676
2003	784654423.62	- 1.22372796	113.5672513	- 4.155108941	14904517649.85	2.932475546	429.787819	0.180879189
2004	915257323.40	4.833657768	128.3367028	1.562578136	16095337093.84	5.104299776	451.6687666	2.28319586
2005	1117113045.65	0.900000001	151.6815663	- 2.294461494	18737897744.79	5.906666082	511.6163943	3.044994854
2006	1273375020.27	5.413807145	167.3764625	2.046914102	25825524820.81	6.472494299	685.9544229	3.576193194
2007	1356199364.86	3.45195249	172.4955966	0.104847755	31958195182.24	6.850729771	825.666555	3.933089234
2008	1611835901.91	4.861712995	198.3528517	1.456551173	35895153327.85	0.232282746	902.0699578	- 2.503375539
2009	1781455092.07	3.812746937	212.1370572	0.455731439	42347217912.92	3.306939815	1035.338787	0.503848174
2010	2032135246.50	5.124163303	234.2355389	1.756244616	45405587556.73	8.058473603	1080.296184	5.156172559
2011	2235820867.83	4.032602496	249.5779794	0.74848923	46869457318.25	5.12110612	1085.487152	2.327212115
2012	2333308099.46	4.446708222	252.3588707	1.198012892	56396706005.94	4.568679614	1271.815383	1.820962224
2013	2451625332.75	4.924195261	256.9756526	1.687375305	61671425370.02	3.797848393	1354.820833	1.115072234
2014	2705783272.07	4.240651644	274.8578362	1.021626356	68285768554.47	5.020111002	1462.220052	2.36632834
2015	3104394858.12	- 3.900003086	305.5496525	- 6.886404541	70120413328.78	4.967721128	1464.554009	2.384487265
2016	2732808556.84	- 0.600020001	260.5652208	- 3.708334877	74815121314.94	4.213517068	1525.235192	1.720986009
2017	2748180473.71	0.500009999	253.8263541	- 2.646778209	82035800868.19	3.815506427	1633.491216	1.397716647
2018	2668495742.88	1.609933082	238.783467	- 1.557543455	92202956320.53	5.62910144	1794.091175	3.221429193
2019	2631434363.23	1.842476677	228.2135892	- 1.294768236	100555485831.94	4.981132628	1912.647867	2.622086845
2020	2841786382.19	0.297577119	238.9907259	- 2.740708463	101013726529.06	- 0.316182729	1878.580703	- 2.535856123

Appendix 7: Historical GDP Share (%) for Burundi (The World Bank, 2022) and Kenya (KNBS, 2004, 2008, 2012, 2016, 2021)

Year	Burundi				Kenya			
	Agriculture	Industry	Transportation	Commercial, Service & Other	Agriculture	Industry	Transportation	Commercial, Service & Other
2000	44.10704	26.44080347	8.682120815	20.770036	26.4	18.9	6.1	48.6
2001	43.843142	26.49800904	8.819763373	20.839086	26.5	18.8	6.3	48.4
2002	43.333611	26.89073459	8.962719559	20.812935	26.4	18.7	6.3	48.6
2003	42.841284	26.78475035	11.5011605	18.872805	25.8	15.6	9.2	49.4
2004	41.902605	27.77385233	12.57529902	17.748244	24.9	16.2	9.9	49
2005	40.848123	28.8180202	10.18456451	20.149292	24.2	17	10.4	48.4
2006	40.637682	25.68249485	10.05701275	23.62281	23.8	16.5	11.3	48.4
2007	34.934172	28.265556	10.88565081	25.914621	22.1	16.4	10.6	50.9
2008	38.004823	25.03773927	12.31698299	24.640454	22.7	17.4	10.3	49.6
2009	36.721364	26.40993033	15.34608138	21.522624	23.9	16.4	9.9	49.8
2010	38.430545	24.63199526	21.1375628	15.799897	22.0	16.3	10.0	51.7
2011	36.704576	24.12867433	22.95928163	16.207468	26.3	19	7.1	47.6
2012	35.420033	24.58138076	22.42469861	17.573888	26.1	18.6	8.0	47.3
2013	38.3674	25.13062047	25.6986169	10.803363	26.4	17.4	7.9	48.3
2014	34.958192	25.62242142	22.26646473	17.152922	27.3	17.9	8.6	46.2
2015	30.684697	20.44298248	11.18775233	37.684568	30.0	17.8	8.4	43.8
2016	31.544336	21.56907954	10.97787846	35.908706	20	18.2	10.2	51.6
2017	28.546647	-	11.55092464	-	20.9	17.4	10.2	51.5
2018	29.0119	-	15.50744563	-	20.3	17.2	11.3	51.2
2019	28.84439	-	-	-	21.2	16.8	11.7	50.3
2020	28.624946	-	-	-	23	17.4	10.8	48.8

Appendix 8: Planned Projects with Electricity Demand (in MW) for Kenya (Government of Kenya, 2018)

Year	Project	Total Power Demand in the specified year
2021	Special Economic Zones	5
2022	Electrified Standard Gauge Railway	98
2024	Mass Rapid Transit Electrification	15
	Konza Techno city	2
2025	Oil pipeline - LAPSSET	50
2030	Mass Rapid Transit Electrification	50
	Electrified Standard Gauge Railway	130
	Integrated steel mills	100
2035	Integrated steel mills	200
	Oil pipeline – LAPSSET	150
	Konza Techno city	190
2037	Special Economic Zones	110

LAPSSET “Lamu Port, South Sudan, Ethiopia Transport”

Appendix 9: Planned Projects with Electricity Demand in Burundi (REGIDESO, 2022)

Industry/ Company	Départ MT de Raccordement	Poste Source de Raccordement	Demand at specific Location	2022	2023	2024	2025	2026	2027	2028	2029	2030
1st Highway Engenieering CO. LTD	Départ Rutana	Poste Itaba	MW - Niveau de l'Usager	0,152	0,155	0,158	0,161	0,165	0,168	0,171	0,175	0,178
			MWh - Niveau de l'Usager	456	466	475	484	494	504	514	524	535
			MW - Niveau du Départ MT	0,170	0,172	0,176	0,178	0,182	0,185	0,189	0,193	0,197
			MWh - Niveau du Départ MT	510	517	527	535	545	556	567	579	590
Jeunesse pour Christ au Burundi	Départ Rugombo	Poste Cibitoke	MW - Niveau de l'Usager	0,152	0,155	0,158	0,161	0,165	0,168	0,171	0,175	0,178
			MWh - Niveau de l'Usager	411	419	427	436	445	454	463	472	481
			MW - Niveau du Départ MT	0,170	0,172	0,176	0,178	0,182	0,185	0,189	0,193	0,197
			MWh - Niveau du Départ MT	459	465	474	481	491	501	511	521	531
Tanganyika Mining Burundi	Départ Buhoro	Poste Cibitoke	MW - Niveau de l'Usager	1,217	1,242	1,266	1,292	1,318	1,344	1,371	1,398	1,426
			MWh - Niveau de l'Usager	4869	4966	5066	5167	5270	5376	5483	5593	5705
			MW - Niveau du Départ MT	1,270	1,295	1,321	1,345	1,372	1,400	1,428	1,456	1,485
			MWh - Niveau du Départ MT	5 078	5 182	5 285	5 382	5 489	5 599	5 711	5 825	5 942
KPC/KAYANZA	Départ Kayanza centre	Poste Kayanza	MW - Niveau de l'Usager	0,152	0,155	0,158	0,161	0,165	0,168	0,171	0,175	0,178
			MWh - Niveau de l'Usager	456	466	475	484	494	504	514	524	535
			MW - Niveau du Départ MT	0,170	0,172	0,176	0,178	0,182	0,185	0,189	0,193	0,197
			MWh - Niveau du Départ MT	510	517	527	535	545	556	567	579	590
TAWAKAL COMPANY	Départ Gashoho	Poste Source Musasa	MW - Niveau de l'Usager	0,243	0,248	0,253	0,258	0,264	0,269	0,274	0,280	0,285
			MWh - Niveau de l'Usager	730	745	760	775	791	806	823	839	856
			MW - Niveau du Départ MT	0,272	0,276	0,281	0,285	0,291	0,297	0,303	0,309	0,315
			MWh - Niveau du Départ MT	815	827	843	855	872	890	908	926	944
Laiterie de Buringa	Muzinda	Poste Bubanza /Gahongoré	MW - Niveau de l'Usager	0,243	0,248	0,253	0,258	0,264	0,269	0,274	0,280	0,285
			MWh - Niveau de l'Usager	852	869	887	904	922	941	960	979	998
			MW - Niveau du Départ MT	0,272	0,276	0,281	0,285	0,291	0,297	0,303	0,309	0,315
			MWh - Niveau du Départ MT	951	964	984	998	1 018	1 038	1 059	1 080	1 102

Industry/ Company	Départ MT de Raccordement	Poste Source de Raccordement	Demand at specific Location	2022	2023	2024	2025	2026	2027	2028	2029	2030
AMAGROUP	Muzinda	Poste Bubanza /Gahongoré	MW - Niveau de l'Usager	0,152	0,155	0,158	0,161	0,165	0,168	0,171	0,175	0,178
			MWh - Niveau de l'Usager	456	466	475	484	494	504	514	524	535
			MW - Niveau du Départ MT	0,170	0,172	0,176	0,178	0,182	0,185	0,189	0,193	0,197
			MWh - Niveau du Départ MT	510	517	527	535	545	556	567	579	590
Usine de la Zone Marumvya	Futur Départ Dédié	Poste Nord	MW - Niveau de l'Usager	2,500	2,625	2,756	2,894	3,039	3,191	3,350	3,518	3,694
			MWh - Niveau de l'Usager	8 750	9 188	9 647	10 129	10 636	11 167	11 726	12 312	12 928
			MW - Niveau du Départ MT	2,608	2,739	2,876	3,014	3,165	3,323	3,489	3,664	3,847
			MWh - Niveau du Départ MT	9 126	9 586	10 065	10 550	11 077	11 631	12 213	12 823	13 464
Peace Park Complex Stadium	Départ Makamba	Poste Itaba	MW - Niveau de l'Usager	0,243	0,248	0,253	0,258	0,264	0,269	0,274	0,280	0,285
			MWh - Niveau de l'Usager	365	372	380	388	395	403	411	419	428
			MW - Niveau du Départ MT	0,272	0,276	0,281	0,285	0,291	0,297	0,303	0,309	0,315
			MWh - Niveau du Départ MT	408	413	422	428	436	445	454	463	472
Aigle Mineral Water	Départ Makamba	Poste Itaba	MW - Niveau de l'Usager	0,243	0,248	0,253	0,258	0,264	0,269	0,274	0,280	0,285
			MWh - Niveau de l'Usager	730	745	760	775	791	806	823	839	856
			MW - Niveau du Départ MT	0,272	0,276	0,281	0,285	0,291	0,297	0,303	0,309	0,315
			MWh - Niveau du Départ MT	815	827	843	855	872	890	908	926	944
Total Specific Projets (Demande en Pointe synchrone avec la Demande de Base à Desservir)			MW en Pointe Synchrone avec Demande de Base - Niveau des Départs MT	4,73	4,87	5,02	5,16	5,32	5,49	5,66	5,84	6,03
			MWh - Niveau des Départs MT	19 181	19 813	20 497	21 152	21 892	22 662	23 464	24 300	25 171

Appendix 10: Projected Efficiencies (%) and Economic ($/kW) data for Power Transmission and Distribution for Burundi and Kenya

Year	Burundi			Kenya		
	Efficiency	Capital cost ($/kW) in 2020	Lifetime (years)	Efficiency	Capital cost ($/kW) in 2020	Lifetime (years)
2015	–	365* – 2502**	50* –70**	–	365* – 2502**	50* –70**
2025	85		–	85		–
2030	90		50* –70**	–		50* –70**
2040	–		50* –70**	–		50* –70**

transmission, ** Distribution

Appendix 11: Projected financial data for Fossil Fuels

In both the countries, the prices of petroleum products have been fluctuating. Accordingly, the fuels prices are expected to change in future. The following Table shows the estimated projected yearly average prices for selected fossil fuels in Africa (Allington et al., 2022).

Projected Prices ($/GJ) for Fossil Fuels in Africa

Commodity	2015	2020	2025	2030	2040	2050
Crude Oil Imports	13.1	12.2	12.8	14.3	16.9	19.5
Crude Oil Extraction	12.0	11.1	11.6	13.0	15.4	17.8
Biomass Imports	1.8	1.8	1.8	1.8	1.8	1.8
Biomass Extraction	1.6	1.6	1.6	1.6	1.6	1.6
Coal Imports	4.9	5.1	5.3	5.5	5.9	5.9
Coal Extraction	3.3	3.4	3.5	3.6	3.8	3.8
Light Fuel Oil Imports	15.9	14.7	15.4	17.3	20.4	23.6
Heavy Fuel Oil Imports	9.6	8.9	9.3	10.4	12.3	14.2
Natural Gas Imports	8.6	8.6	9.5	10.3	11.0	11.0
Natural Gas Extraction	7.1	7.1	7.8	8.5	9.9	9.9
Peat	-	-	-	-	-	-
*Nuclear	11.6	11.6	11.6	11.6	11.6	11.6

*(Government of Kenya, 2018).

Appendix 12: Projected capital costs ($/kW) for RE and non-RE power technologies

In power technologies, prices for RE are expected to significantly drop compared to fossil fuels prices. The following Table provides projected prices for RE technologies in Africa (Allington et al., 2022; Pappis, I., Howells, M., Sridharan, V., Usher, W., Shivakumar, A., Gardumi, F., Ramos, 2019).

Technology	RE Technologies							Technology	Non-RE Technology		
	2015	2020	2025	2030	2040	2050			2015	2030	2050
Biomass	2500	2500	2500	2500	2500	2500		Coal+ CCS	4500	4100	3700
Geothermal	4000	4000	4000	4000	4000	4000		Oil-Diesel centralized	1200	1200	1200
Solar PV (Utility)	2165	1378	984	886	723	723		NG- CCGT+ CCS	2450	2200	2000
CSP with Storage	8645	5797	4670	3763	3660	3660		Nuclear	4000	4000	4000
Hydropower	3000	3000	3000	3000	3000	3000		Peat			
Onshore Wind	1985	1489	1191	1087	933	933		/////	///////	//////	///////

CCS: Carbone Capture Storage

Appendix 13: Historical Imports of Oil products (in Millions of USD) and NG

Year	Burundi	Kenya
2000	-	-
2001	-	-
2002	-	-
2003	21.97	849.00
2004	26.53	1121.00
2005	38.12	1266.00
2006	57.54	1577.00
2007	-	-
2008	95.50	2925.32
2009	57.00	2067.00
2010	98.40	2534.04
2011	147.00	3803.02
2012	143.00	3867.60
2013	148.00	3386.12
2014	154.00	3817.82
2015	207.88	2303.21
2016	97.10	1946.71
2017	118.91	2565.32
2018	146.57	3213.82
2019	148.71	3104.26
2020	131.58	2050.52

Source: (EAC, 2021b) (Millions of USD)

Appendix 14: Monthly peak load (presented in MW for Kenya) and monthly peak load (presented in kW for Burundi) monthly energy generation for Burundi)

Month	Burundi Peak (kWh) – year 2016	Kenya Peak (MW) – year 2018
January	22 712 538	1770
February	22355 176	1768
March	24333788	1731
April	24675928	1744
May	25818 08	1758
June	24 193 671	1802
July	24389448	1812
August	24316515	1832
September	23 348 366	1814
October	24844 22	1830
November	23519414	1859
December	22933989	1845

Source: for Burundi (REGIDESO, 2016), for Kenya (Ministry of Energy Report, 2019)

Appendix 15: Research Output

1. E. Manirambona, S. M. Talai, and S. K. Kimutai, "A review of sustainable planning of Burundian energy sector in East Africa," *Energy Strategy Reviews*, vol. 43, no. July, p. 100927, 2022, https://doi.org/10.1016/j.esr.2022.100927.
2. E. Manirambona, S. M. Talai, and S. K. Kimutai, "Sustainability evaluation of power generation technologies using Multi-Criteria Decision Making : The Kenyan case," *Energy Reports*, vol. 8, pp. 14901–14914, 2022, https://doi.org/10.1016/j.egyr.2022.11.055.
3. E. Manirambona, S. M. Talai, and S. K. Kimutai "Mapping Kenyan Total Energy Flow Using Sankey Diagrams", 10th Chuka University Annual International Research Conference - Mainstreaming Research Innovation and Technology-transfer and Commercialization for Sustainable Economies (MRIT-TCSE), 5th October 2023, ***Presented.***
4. E. Manirambona, S. M. Talai, and S. K. Kimutai, "Appraising Kenyan energy demand policies for energy efficiency improvement and GHG emissions mitigation", *Energy Strategy Reviews*, ***Under Review***.

Appendix 16: Plagiarism Certificate

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Awarded by:

Prof. Anne Syomwene Kisilu

CERM-ESA Project Leader Date: 14/07/2023