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School of Industrial & Information Engineering
Master of Science in Energy Engineering

Definition & Analysis of Alternative Electric Power Generation Scenarios in Kenya

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"O' MY LORD INCREASE ME IN KNOWLEGE"
Quran
Surah Taha 114

To my parents

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ABSTRACT

The strategic development goals envisioned by the United Nations include the universal access to modern energy services for all by 2030. In Kenya only about 46% of the population currently has access to electricity, in addition the electrified areas suffer from significant number of hours of power outages.

This thesis analyses multiple scenarios, and selected implications, investigating pathways that would allow the country to reach its electrification targets and meet the power demand at the lowest possible cost. The modeling tool which is used for the purposes of this study is OSeMOSYS. This techno-economic modeling software shows the optimal energy mix in order to meet the demand for electricity at the lowest possible cost while considering the constraints. The scenarios considered were GoK Policies Scenario, New Policies Scenario & 100% Renewable Scenario. Indicatively, results show that Geothermal, Nuclear technologies will provide the base load capacity while Natural gas power plants are favored for peak load demand. A high penetration of off grid power generation technologies especially solar photo-voltaic is observed in all the three scenarios.

The comparison of scenarios illustrate that power production from 100% renewable sources in Kenya will not have a significant effect on the optimal energy mix since most of the power production as of now is also from renewable power generation technologies i.e. hydro and geothermal. However this would require a huge capacity investment in geothermal, nuclear and solar off-grid technologies and an investment in Natural gas open and combined cycle technologies to provide the back-up capacity.

EXECUTIVE SUMMARY

The strategic development goals envisioned by the United Nations include the universal access to modern energy services for all by 2030. In Kenya only about 46% of the population currently has access to electricity, in addition the electrified areas suffer from significant number of hours of power outages. The cost of electricity in Kenya is also substantially high compared to other developing countries like India and China.

The demand of electricity in Kenya is forecasted to grow at a high rate as the economic growth in the country picks up a rate higher than 5% estimated by the World Bank. This will boost the electricity demand in industry and also in the residential and commercial sectors. The power mix of Kenya in 2017 comprise largely of Renewable technologies (72%). Hydro power plants provide most of this capacity followed by the geothermal power plants. Hydroelectric power generation in Kenya is highly sensitive to seasonal changes and hence not very reliable source of power. Geothermal technology however provides a consistent base load capacity for power generation in Kenya.

This thesis analyses multiple scenarios, and selected implications, investigating pathways that would allow the country to reach its electrification targets and meet the power demand at the lowest possible cost. The modeling tool which is used for the purposes of this study is OSeMOSYS. This techno-economic modeling software finds the optimal energy mix in order to meet the demand for electricity at the lowest possible cost while considering the constraints.

Three scenarios are considered for analysis. GoK Policies Scenario, based on Least Cost power Development Plan of Government of Kenya New Policies Scenario based on the Africa Energy Outlook Report by International Energy Agency & 100% Renewable Scenario which assumes all the same parameters except the share of renewables in the power generation mix is considered to be 100%. The intentions of government to invest in a particular technology such as Nuclear are considered in the case of GoK policies Scenario. In the New Policies Scenario no restriction is applied on the model and the model is free to choose the cost efficient option.

The analyses of the results reveal that solar roof top technologies will play a key role in the electrification of the areas that lack access to the grid. Diesel distributed generation is set to compliment the solar roof top technologies providing the back-up capacity in night times and in bad weather situations.

Geothermal power generation emerges as the least cost option among the on-grid technologies. Kenya is a country endowed with massive geothermal potential. Geothermal Development Authority formed by the Govt. of Kenya has already

implemented 513 MW of geothermal capacity with further capacity development in progress.

Natural Gas power plants are also observed to comprise the energy mix even in the case of 100% renewable scenario where it serves only as a back-up capacity. Natural gas power plants are considered as a source of clean power generation among the thermal power plants. The CO_2 emissions arising from the activity of thermal power generation technologies in each scenario are also quantified and reported in this thesis.

Contents

List of figures

List of tables

Nomenclature

Acronyms, abbreviations

KPLC	*Kenya Power & Lighting Company*
KENGEN	*Kenya Electricity Generation*
KETARCO	*Kenya Electricity Transmission Company*
GDC	*Geothermal Development Company*
KNEB	*Kenya Nuclear Electricity Board*
IPP	*Independent Power Producers*
ERC	*Energy Regulatory Commission*
MoEP	*Ministry of Energy & Petroleum*
REA	*Rural Electrification Authority*
AfDB	*African Development Bank*
CCGT	*Combined Cycle Gas Turbine*
SCGT	*Single Cycle Gas Turbine*
CSP	*Concentrated Solar Power*
HFO	*Heavy Fuel Oil*
STPP	*Steam Turbine Power Plant*
PV	*Photovoltaic Cell*
GW	*Giga (10^9) Watt*
PJ	*Peta (10^{12}) Joules*
MUSD	*Million (10^6) US Dollars as @ June 2017*

Foreword

The thesis is the result of study & research in the field of Energy Engineering-Energy for Development, carried out at *Department of Energy*, *Politecnico di Milano*, Italy and Faculty of Engineering Science & Technology at Technical University of Kenya, Nairobi.

To develop the energy model data was collected from Kenya Power Institute of Research & Training, Ken Gen, HIVOS East Africa & Kenya National Bureau of Statistics.

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1 INTRODUCTION

1.1 Background

The primary purpose of our energy system is to contribute to a better quality of life. To those that have it, modern energy unlocks access to improved healthcare, improved education, improved economic opportunities and, even, longer life. To those that don't, it is a major constraint on their social and economic development. The factors that account to define the quality of life include:

- **Improved Water Access**: Proportion of the population using improved drinking water sources, such as public tap, tube well, and protected springs.
- **Life Expectancy at Birth**: The number of years a newborn infant would live if the mortality patterns at the time of birth prevail throughout the individual's life.
- **Infant Mortality Rate**: The number of infants that die before reaching one year of age, per 1000live births in a given year.
- **Mean Years of Schooling**: Lifetime number of years of education received by individuals ages 25 and older.

The results presented in the paper Energy & Quality of Life (Pasten & Santamarina, 2012) illustrates that all the above depend strongly on the electrification level and the energy consumption rate. Hence the higher the electrification level and the energy consumption rate the higher the quality of life and higher the Human Development Index (HDI).

Energy access is one of the most critical parameters from an economic, environmental and developmental perspective that the world is facing today. Energy access is a way out of poverty, increasing the productivity and improved health from a population perspective. Yet to this day one in five people still lacks access to modern electricity and approximately 3 billion people rely on wood, coal, charcoal or animal waste for cooking and heating.

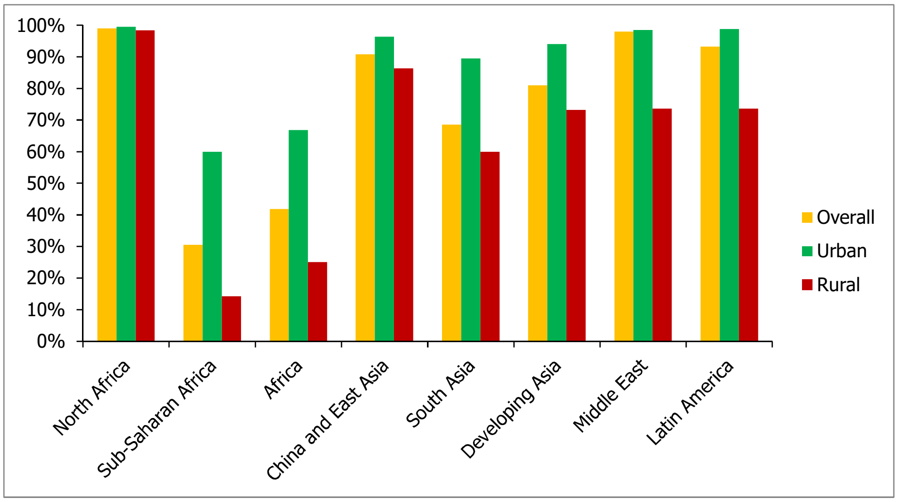

Figure 1 Energy Access in different regions of the World. (UNDP, 2011)

On September 25th 2015, United Nations adopted a set of goals to end poverty, protect the planet and ensure prosperity for all as part of a new sustainable development agenda. As part of this agenda 17 Sustainable Development Goals (SDG's) are identified (United Nations, n.d.). Each goal has specific targets to be achieved over the next 15 years. The goal number 7 of the sustainable development goals is the Ensure access to affordable, reliable, sustainable and modern energy for all. This goal identifies the following:

- By 2030, ensure universal access to affordable, reliable and modern energy services
- By 2030, increase substantially the share of renewable energy in the global energy mix
- By 2030, double the global rate of improvement in energy efficiency
- By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology
- By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programs of support.

1.2 Energy Situation in Sub-Saharan Africa

The continent of Africa is the world's second largest continent after Asia and also is the home to second largest population of the world. It is a continent rich in natural resources and wild life. However the region is one of the poorest in the world in terms of economy, human development index. Energy is a central issue to improved social and economic well-being, and is indispensable for industrial and commercial wealth generation.

> "A better functioning energy sector is vital to ensuring that the citizens of sub-Saharan Africa can fulfill their aspirations, the energy sector is acting as a brake on development, but this can be overcome and the benefits of success are huge."
>
> **Maria van der Hoeven**
> **IEA Executive Director**

Sub-Saharan Africa has more people living without access to electricity than any other world region – more than 620 million people, and nearly half of the global total. It is also the only region in the world where the number of people living without electricity is increasing, as rapid population growth is outpacing the many positive efforts to provide access. In 37 sub-Saharan countries the number of people without electricity has increased since 2000 while the regional total rose by around 100 million people. (International Energy Agency, 2014)

Africa's energy sector is vital to its development and yet is one of the most poorly understood parts of the global energy system. Since 2000, much of sub-Saharan Africa has experienced more rapid economic growth than in the past, raising expectations of a new phase of development. Policies are being put in place in many countries aimed at securing a much-needed expansion in domestic energy provision.

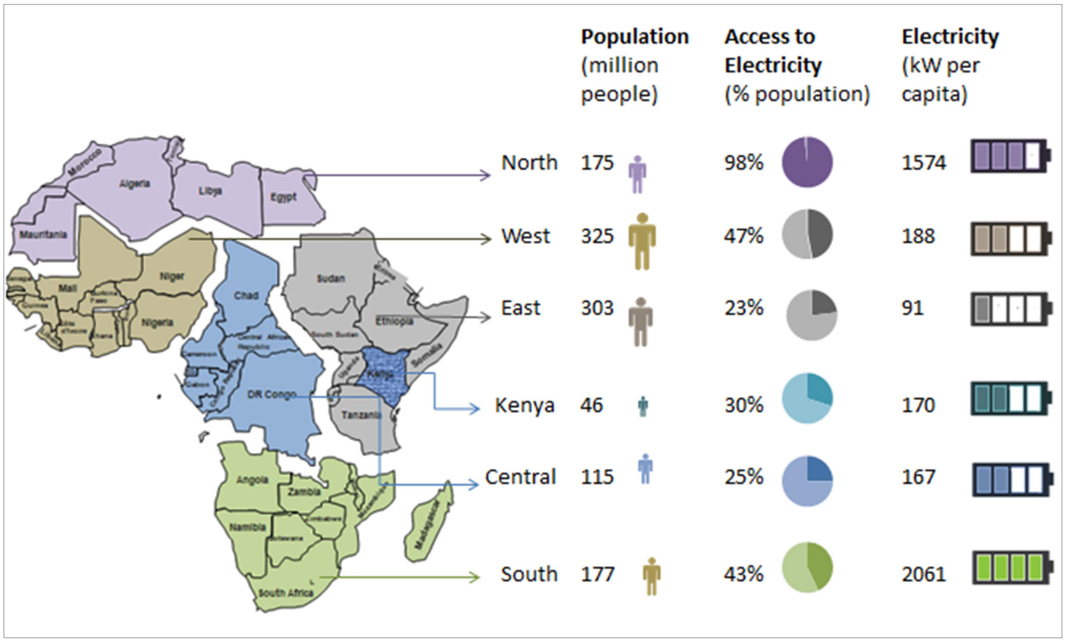

Figure 2 Energy Situation in Kenya with respect to the rest of Africa. (USAID, 2016)

However, the current state of the energy system represents a major threat to the realization of the region's economic hopes.

1.3 Energy Situation in Kenya

Kenya with its 46 million population and abundant natural resources is a major country in the East Africa. In Kenya only 46% of the population has access to electricity (2015) (USAID, 2016) which leads the majority of the population to rely on traditional hazardous fuels for energy such as firewood, charcoal, kerosene. The electricity consumption in Kenya is 170 kW per capita which is quite low mainly due to the fact that majority of the population has no access to electricity.

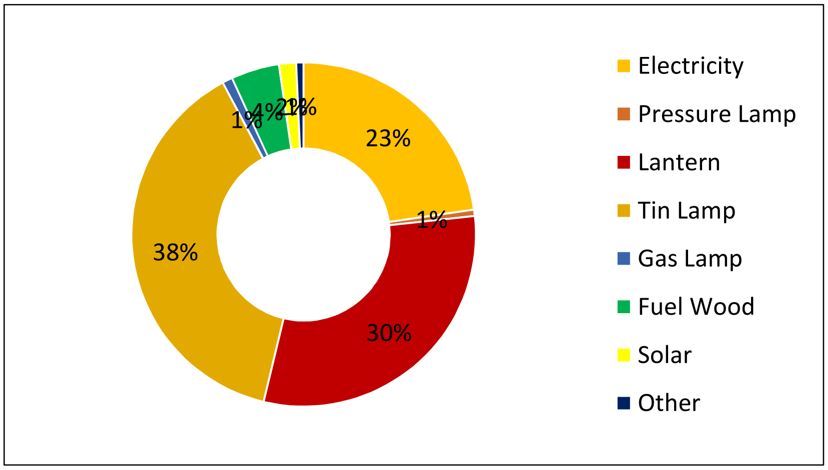

Figure 3 House hold source of lighting (Kenya National Bureau of Statistics, 2009)

During the past decade there has been a significant improvement in electricity access in Kenya (*Figure 4*) but still the national electrification rate is quite low. Also there is a great disparity between the urban and the rural electrification rates. Several ongoing initiatives by the international organizations and the Kenyan government aim to increase the electricity access especially in the rural areas. The rural Electrification Authority set up by the Kenyan government is tasked with development of off-grid and mini grid solutions for the rural communities far from the grid also Power Africa-USAID-project aims at developing off-grid and small scale energy solutions for the distributed communities far from the grid. The initiatives taken by the African Development Bank 'The Last Mile Connectivity Project' aims to support the Government's initiatives of ensuring increased electricity access to Kenyans. The project aims to exploit existing distribution transformers to the maximum through extension of low voltage network to reach households lying within transformers protections distance. It also aims at implementing the new distribution system in order to increase new customer connections.

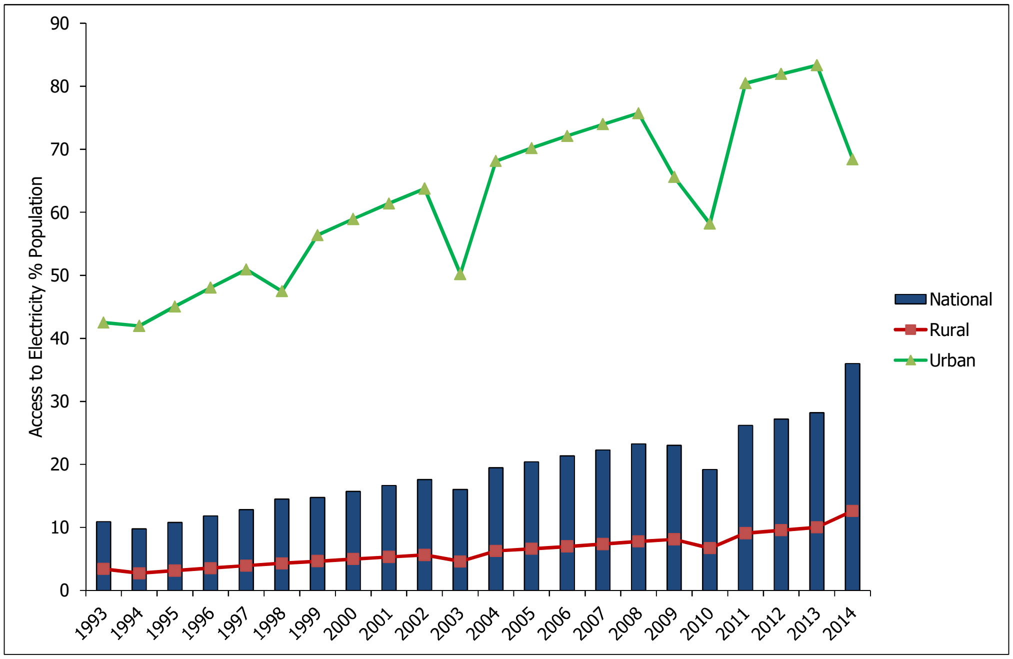

Figure 4 Historical electrification Rate in Kenya. (The World Bank, n.d.)

1.4 Objective of Research

The Kenyan government in its Vision 2030 envisages the universal access of electricity in Kenya by 2020. The establishment of the need for immediate provision of reliable cheap and clean energy for all in Kenya now demands the investigation of various pathways available for electrification in Kenya and the techno economic analysis of those pathways in order to identify the best possible energy policy direction.

The purpose of this thesis is to provide the policy makers with an analysis tool that identifies implications of different energy policies. This is achieved by developing the energy model using the latest modeling tool which investigates the fuel usage & investment requirements in certain power generation, transmission and distribution technologies to meet the demand of electricity while minimizing the cost of electricity.

Using the scenario based modeling approach two scenarios are analyzed first ‘GoK Policies Scenario’ which involves the implementation of government policies and the other called the ‘New policies Scenario’ defined by the International Energy Agency (IEA).

The thesis also involves the identification of key parameters affecting the technological mix hence the electrification pathways and the different ways in which these parameters can slightly or drastically change.

2 FOCUS ON KENYA

2.1 Institutional Structure for Electricity

The State Department of Energy is subsidiary of Ministry of Energy and Petroleum and is mandated to undertake following functions:

- National Energy and Policy management
- Hydro-power Development
- Geothermal Exploration and Development
- Rural Electrification Programme
- Promotion of Renewable Energy
- Energy Regulation, Security, and Conservation

The following semi-autonomous institutions are involved in the regulation, generation, transmission and distribution of electricity.

2.1.1 The Energy Regulatory Commission (ERC)

ERC is an independent agency responsible for regulation of the energy sector agencies, oversight, coordination preparation of Least Cost Power Development Plans (LCPDP), and monitoring and enforcement of sector regulations.

2.1.2 The Kenya Power and Lighting Company (KPLC)

KPLC limited is the power off-taker from power generators on the basis of negotiated Power Purchase Agreements for transmission, distribution and supply to consumers. KPLC is a limited liability company, listed on Nairobi Stock Securities Exchange, with Government's shareholding of 51% while the rest is privately owned.

2.1.3 The Kenya Electricity Generating Company (KenGen)

KenGen is the main player in electricity generation accounting for 1,238MW (76%) of installed electricity generation capacity for the national transmission grid as at 30th June 2013. It is a limited liability company listed in Nairobi Stocks Securities Exchange, with Government shareholding of 70% while the rest is privately owned.

2.1.4 Rural Electrification Authority (REA)

REA is a government wholly owned entity, charged with implementing the Rural Electrification Programme. It came into operation in July 2007.

2.1.5 Geothermal Development Company (GDC)

GDC is a fully owned Government Special Purpose Vehicle (SPV) that undertakes surface exploration of geothermal fields, explorations, appraisals, drilling, steam production and entering into steam sales agreements with investors in the geothermal electricity generation.

2.1.6 Kenya Electricity Transmission Company (KETRACO)

KETRACO was incorporated in December 2008, is a fully owned State Corporation and a Special Purpose Vehicle to plan, design, construct, own, operate and maintain new high voltage (132kV and above)electricity transmission grid and regional inter-connectors.

2.1.7 Kenya Nuclear Electricity Board (KNEB)

KNEB is charged with spearheading and fast tracking development of nuclear electricity generation to enhance production of affordable and reliable electricity.

2.1.8 Independent Power Producers (IPPs)

IPPS are private investors in the power sector involved in generation either on a large scale or for the development of renewable energy under the Feed-in–Tariff (FiT) Policy.

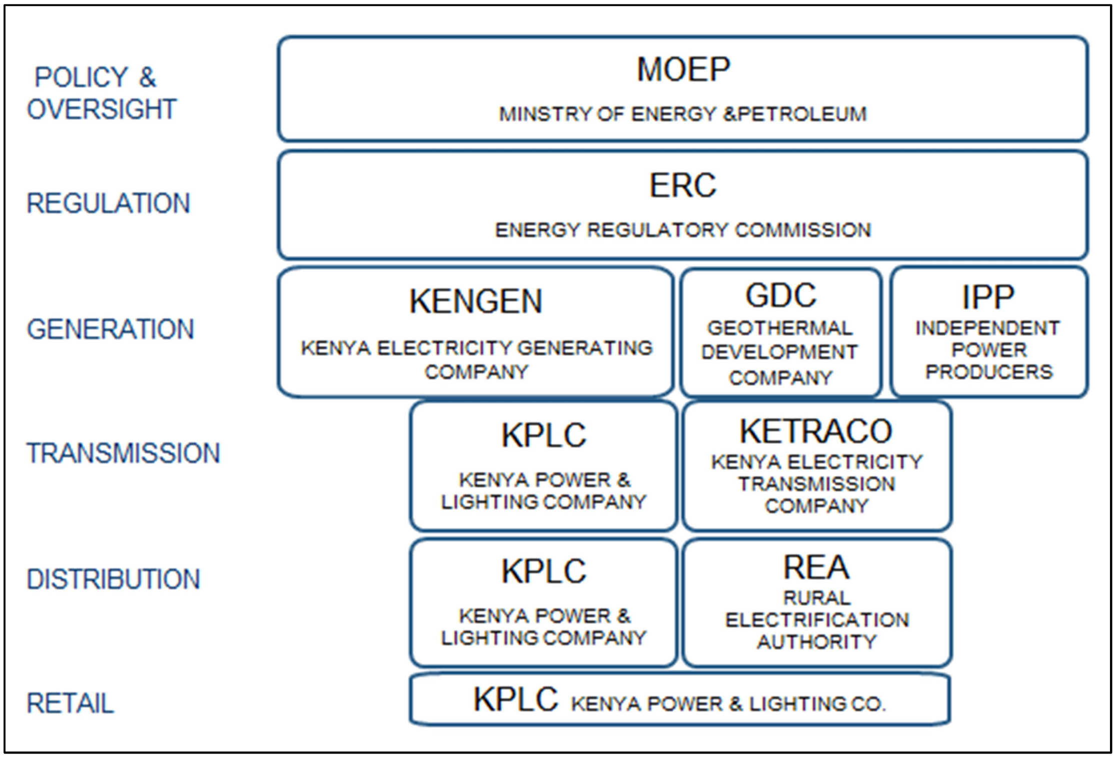

Figure 5 Institutional Structure of Kenya Power Sector.

2.2 Current Status of Electricity Access

Kenya is among the most populous countries in east Africa, and has largest population both with and without access to electricity. The energy sector in Kenya is largely dominated by petroleum and electricity, with wood fuel providing the basic energy needs of the rural communities, urban poor, and the informal sector. [KENYA ENERGY SITUATION] Electricity access in Kenya is low despite the government ambitious targets to achieve universal access by 2030 as of now the status of electricity access lies around 46%. Kenya established a Rural Electrification Authority to further accelerate the electrification of Rural areas. As of 2013, 90% of public facilities have access to electricity, but household access remains low. (International Energy Agency, 2014)

2.3 Cost of Electricity

The cost of electricity in Kenya is very high compared to the developing countries like India and China as illustrated in *Figure* ***6***. (International Energy Agency, 2014)

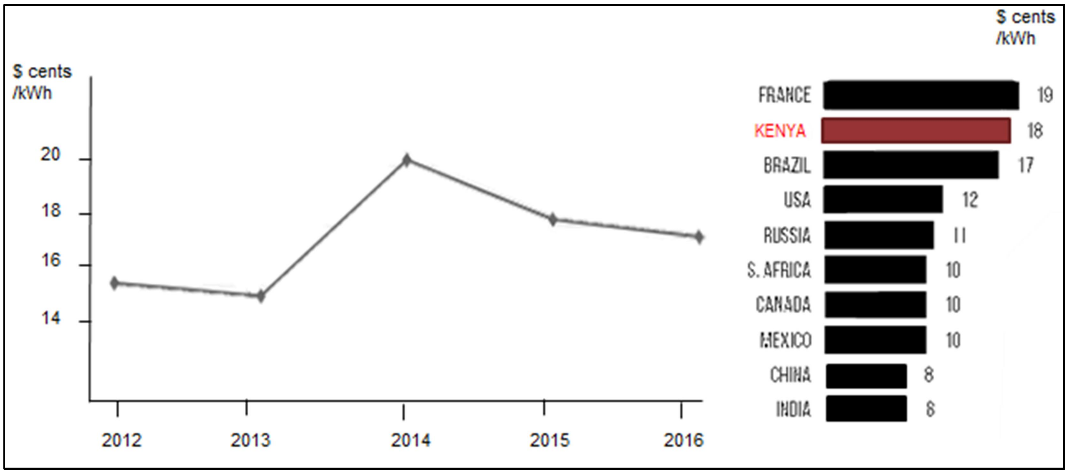

Figure 6 Historical cost of electricity in Kenya & cost of electricity in different countries in 2011.

Figure 7 illustrates the cost of electricity from different power generation technologies in Kenya. The per kWh cost is calculated by dividing the amount paid to the power plants (capacity costs + fuel costs) by the total number of units (kWh) produced by that power plants. Numbers are based on data form 'Kenya Power Annual Financial Statements Report 2017'. (KPLC, 2017)

A big variation is seen in the costs of electricity produced from different technologies because some of the power plants like HFO produced a very small amount of the total electricity demand however they were paid a large amount of capacity charge which increased their overall cost.

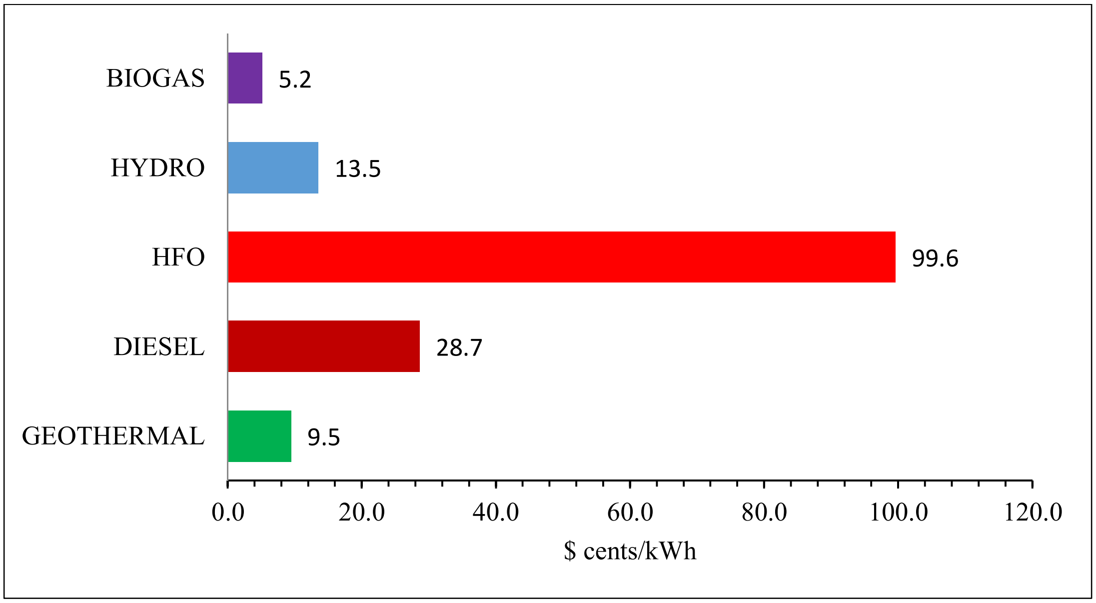

Figure 7 LCOE from different technologies in Kenya. (KPLC, 2017)

2.4 Installed Capacities

Kenya has an installed capacity of 2.3 GW. Whilst about 57% is hydro power, about 32% is thermal and the rest comprises geothermal and emergency thermal power. Solar PV and Wind power play a minor role contributing less than 1%. However, hydropower has ranged from 38-76% of the generation mix due to poor rainfall. Thermal energy sources have been used to make up for these shortfalls, varying between 16-33% of the mix Kenya's current effective installed (grid connected) electricity capacity is 1,429 MW. Electricity supply is predominantly sourced from hydro and fossil fuel (thermal) sources. This generation energy mix comprises 52.1% from hydro, 32.5% from fossil fuels, 13.2% from geothermal, 1.8% from biogas cogeneration and 0.4% from wind, respectively. Current electricity demand is 1,600 MW and is projected to grow to 2,600-3600 MW by 2020.

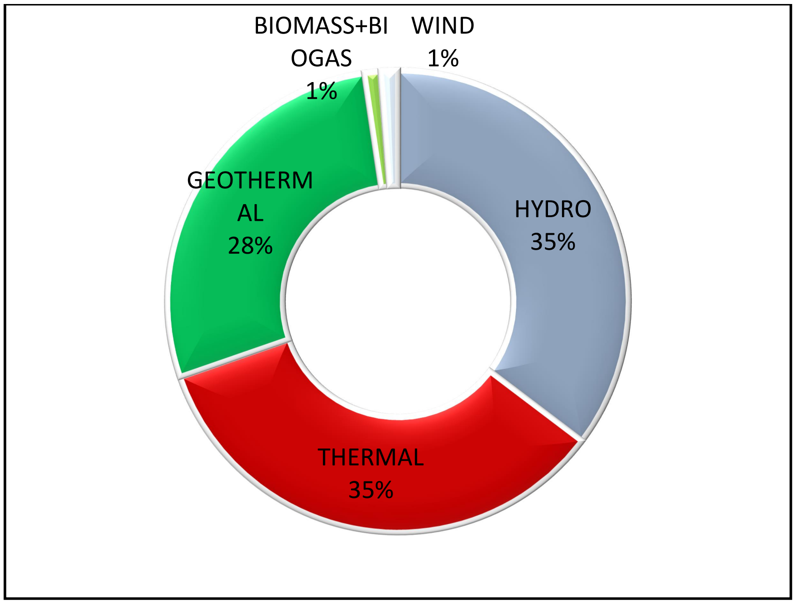

Figure 8 Share of total installed capacity based on Fuel. (KPLC, 2017)

Power Plants	Capacity [MW]	
HYDRO		
Tana	20	20
Kamburu	94.2	90
Gitaru	225	216
Kindaruma	72	70.5
Masinga	40	40
Kiambere	168	164
Turkwel	106	105
Sondu Miriu	60	60
Sangoro	21	20
Small Hydro	11.7	11.2
Total Hydro	818	797
THERMAL		
Kipevu 1 Diesel	73.5	52.3
Kipevu 3 HFO	120	115
Embakasi Gas Turbine	30	28
MuhoroniGas Turbine	30	27
Garissa & Lamu	-	-
Garissa Temporary Plant (Aggreko)	-	-
Total Thermal	254	222

GEOTHERMAL		
Olkaria 1	45	44
Olkaria2	105	101
Eburru Hill	2.5	2.2
Olkaria Mobile Wellheads OW37, OW 37 kwg 12, OW 37 kwg13 & OW 39	20	17.2
Olkaria Mobile Wellheads OW 43	12.8	12.8
Olkaria Mobile Wellheads OW905, OW914, OW915 & OW919	47.8	47.8
Olkaira 4	140	140
Olkaria 1 Units 4 & 5	140	140
Total Geothermal	513	505
WIND		
Ngong	25.5	25.5
TOTAL CAPACITY KENGEN	**1610**	**1549**

Table 1 Installed Capacity of KenGen Operated Power Plants. (Lahmeyer International, 2016b)

Power Plant	Technology	Capacity [MW]	
		Installed	Effective
OrPower 4 Inc.	Geothermal Power Plant	139	139
Iberafrica Power	Diesel Power Plant	108.5	108.5
Triumph Power Generating Company	Medium Speed Diesel Power Plant	83	83
Rabai Power Ltd.	Diesel Power Plant	90	90
Gulf Power Ltd.	Heavy Fuel Oil Power Plant	80.32	80.32
Tsavo Power Company Ltd.	HFO (Heavy Fuel Oil) Power Plant	74	74
Thika Power Ltd.	Diesel Power Plant Combined Cycle	87	87
Regen Terem	Hydro Power Plant	5	5
BioJoule Kenya Ltd.	Biogas Power Plant	2	2
Mumias Sugar Company Ltd.	Biomass Power Plant	26	21.5
Imenti Tea Factory	Micro Hydro Power Plant	0.3	0.3
IPP's TOTAL		695	691

Table 2 Installed Capacity of Independent Power Producers. (Lahmeyer International, 2016b)

Power Plants	Capacity [MW]	
	Installed	Effective
Thermal	26.2	17
Solar	**0.55**	**0.52**
Wind	0.66	0.494
REA Total	**27**	**18**

Table 3: Installed Capacity of Independent Power Producers. (Lahmeyer International, 2016b)

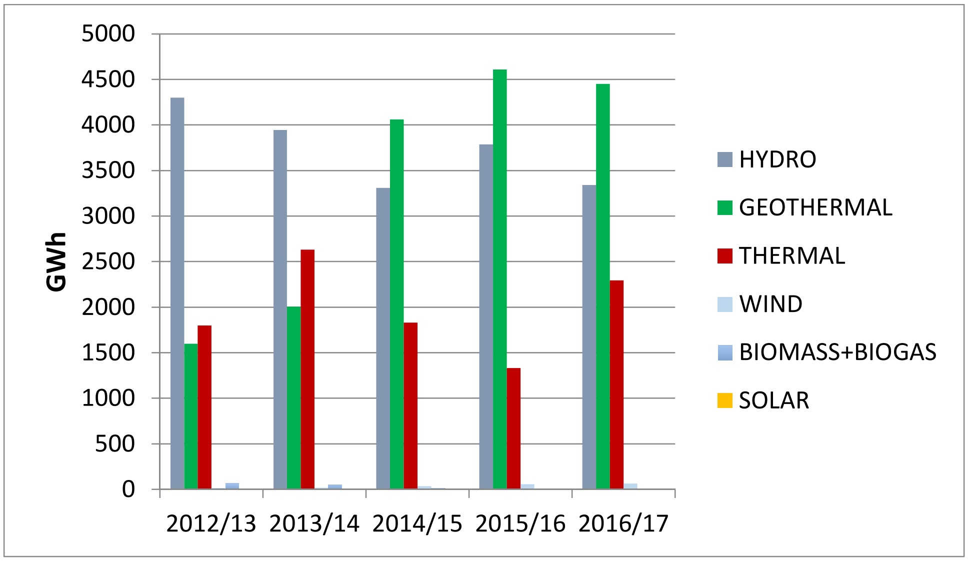

Figure 9: Historical energy production from different fuel sources. (KPLC, 2017)

2.5 Transmission and Distribution Network Infrastructure

The Kenyan electricity supply industry structure is of the single buyer model with all generators selling power in bulk to KPLC for dispatch and onward transmission and distribution to consumers.

The transmission network is managed by KETARCO and comprises of a 220 kV national grid branching into 132 kV and 66 kV levels. The existing network was designed for an operating voltage level up to 220 kV. The nominal fundamental system frequency is 50 Hz.

The transmission network is divided into four main areas namely Nairobi, Coast, Mount Kenya and Western. In spite of the governments ambitious initiatives there the northern and central part of Kenya still lacks transmission infrastructure. However there are plans to rapidly extend the transmission lines

The transmission and distribution network of Kenya is not the most promising one and suffers significant amounts of losses. KPLC reported a 17.6% loss on the gross national consumption in financial year 2014/2015.

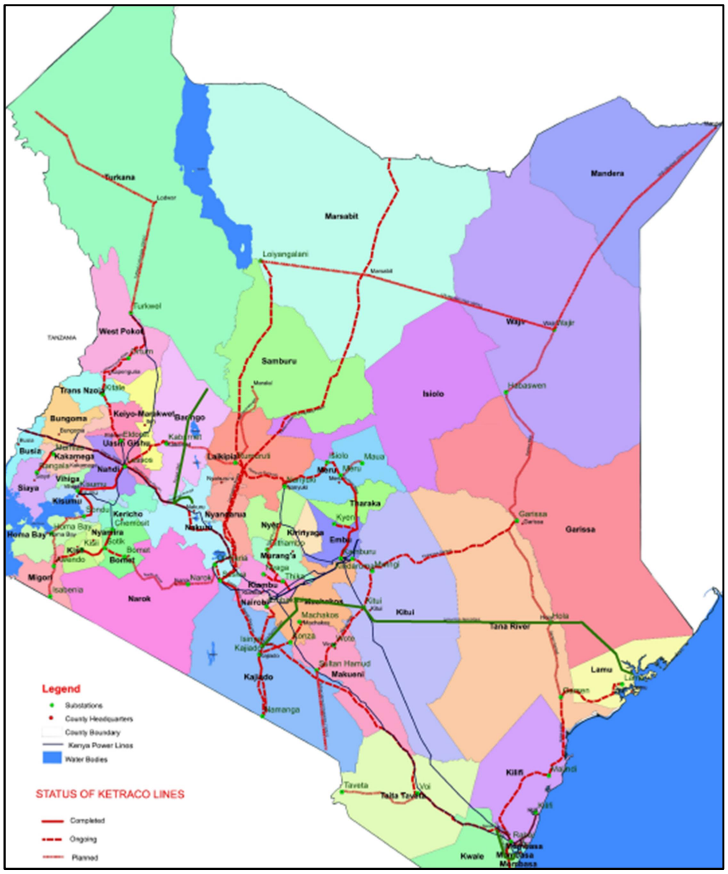

Figure 10 Transmission Network of Kenya-Existing and planned transmission lines. Source KETARCO

3 INDIGINEOUS RESOURCES & CHALLENGES FOR POWER PRODUCTION

Kenya is a country which is rich in renewable energy resources. It is endowed with a huge potential of hydro in the Moi Basin and geothermal resources in the Rift valley. It receives a significant amount of solar radiation throughout the year, which accounts for a significant potential of solar power production.

No significant reserves of oil and gas have been discovered in Kenya and Kenya depends on oil and gas imports to operate its thermal power plants.

A detailed analysis of the resources available in Kenya for power production is given in this chapter.

3.1 Hydro Power

Hydro power is one of the most important energy resources in Kenya providing 35% of the total installed capacity for power production. Kenya's water flow system comprises of five major basins, Tana River, North-Eastern, Athi and coastal area, Lake Victoria , Ewaso-Nyiro and Rift Valley. These basins contain the major portion of the country's inland hydro resources. The total hydropower technical resource is estimated to be about 6 GW (Energypedia, n.d.), with half this potential being attributed to small rivers. The hydro resources lie in areas of high domestic energy demand.

The hydroelectric power potential of economic significance available for large scale power development is estimated to be 1,500 MW of which 1,310 MW is for projects of 30 MW or bigger. Of this, 434 MW has been identified in the Lake Victoria basin, 264 MW in the Rift Valley basin 109 MW on Athi River basin, 604 MW on Tana River basin and 146 MW on Ewaso Ngiro North River basin. On the Tana River and Ewaso Nyiro basins, a further 420 MW have also been identified. (Energypedia, n.d.)

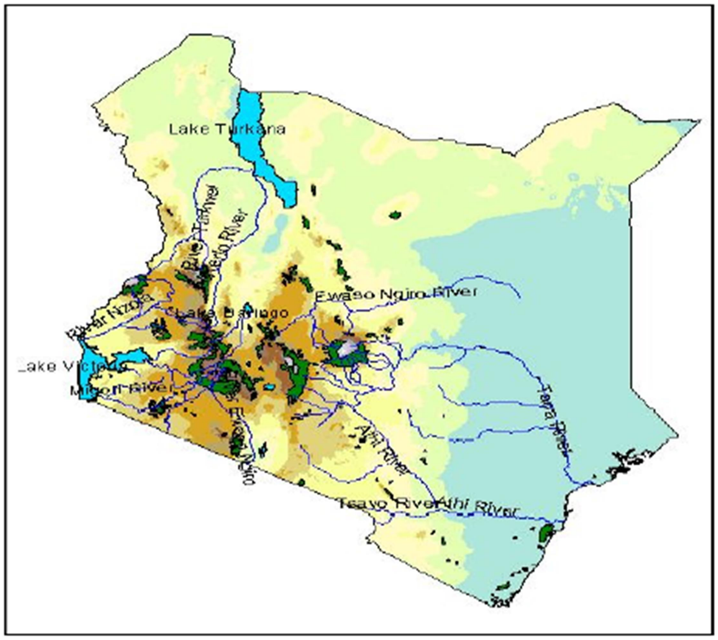

Figure 11 Major river basins in Kenya. (zce kenya)

As of 2017, Kenya's hydropower stations have had a total installed capacity of 818 MW (KPLC, 2017). The complete list of hydro power plants along with their installed capacity is given in Tab.1.

Power plants less than 10 MW capacity Small, mini and micro hydro systems are estimated at 3,000 MW nationwide. In 1997, Kenya's Electric Power Act allowed independent power producers to supply electricity to the grid, but small decentralized schemes, such as micro hydropower, were not fully addressed. Micro hydropower is not new to Kenya; prior to the 1960s micro hydro was used to power grain mills. However, these out-dated systems were quickly outpaced by the diesel engine for milling grain. Mini and micro hydropower in Kenya was among the earliest recognized sources of electricity in the early 1900s. Approximately 55 river sites have been identified as attractive commercial possibilities, with maximum mean capacities in the range of 50 kW to 700 kW. These are useful for off-grid or isolated grid rural electrification. Unlike large-scale hydro-projects, small-scale hydro is more environmentally suitable in remote off grid areas.

Today, improved technology makes micro hydropower economically viable in many situations, but the country lacks the infrastructure for production and installation of micro hydro systems, or for repair of systems once they are installed. In addition, there are no standards or other policies to encourage and enable local communities to take advantage of this renewable and environment friendly source of power.

The challenges faced in the development of the Hydro power resource exploitation infrastructure as identified by the ERC are following:

1. Hydropower is vulnerable to variations in hydrology and climate. This is a big challenge as poor rains results in power and energy shortfalls, reducing the contribution of hydro power in the energy mix.

2. The economic risk in hydropower projects is relatively higher than other modes of electricity generation because they are capital intensive and wholly dependent on hydrology.

3. A major challenge for hydro power projects is relocation and resettlement of affected persons. This is key among reasons why the Magwagwa hydro project on river Kipsonoi in Kericho, a densely populated area, has not been implemented to date.

4. Long lead time of between 7-10 years.

5. Inadequate hydrological data throughout the East African region that neither captures quality nor cover required periods of at least 50 years.

6. Water charges that have an effect of increasing the cost of hydro generated electricity.

7. Conflicting and competing land and water uses between various sub-sectors of the economy with regard to development and utilization of the same for electricity generation.

8. Ownership of physical dam reservoirs which have stifled redevelopment.

3.2 Fossil Fuels

Fossil energy sources are defined as hydrocarbon deposits formed in the geological past from the remains of living organisms. In this study they are differentiated by their texture and aggregate state, i.e. liquid, solid and gaseous energy sources.

At present, coal is the only domestic fossil energy resource available for extraction and potential use in power generation. Exploration activities on crude oil and natural gas deposits are underway and for gas still in the appraisal stage.

3.2.1 Crude Oil

Crude oil is a liquid fossil fuel consisting of a complex mixture of hydrocarbons found in and extracted from geological formations beneath the Earth's surface. It is the source of a wide range of liquid, gaseous and solid petroleum products produced in refineries.

During the past 50 years, crude oil has been the major energy source in the world measured by energy content. This is due to its dominance in the transport sector. For electricity generation it plays a less dominant role, though it is still important for some petroleum products (such as gasoil and HFO) as well as for selected oil producing countries. In Kenya imported petroleum products such as HFO and diesel oil, are used in thermal power plants for power generation purposes.

Kenya's electricity sector relies considerably on imported crude oil and petroleum products fuelling nearly 40% (Lahmeyer International, 2016b)the country's installed power generating capacity in 2014. With the commissioning of geothermal power plants this dependency has decreased to 35% (*Figure **9***) in recent years. All petroleum products used in Kenya are imported including crude oil as well as refinery products. Imported crude oil was refined in the Kenya Petroleum Refineries Limited (KPRL) and processed into various petroleum products for use in domestic power generation until its operation stopped in 2013. Approximately three quarters of the crude oil is imported into Kenya from Abu Dhabi referred to as "Murban crude" and the remaining one quarter is imported from Saudi Arabia referred to as "Arabian Medium". Murban crude oil variety is of higher quality as it produces more diesel, gasoline, kerosene and less heavy fuel oil than the Arabian Medium variety.

Kenya has four major basins in which the oil exploratory activities have been carried out namely Lamu, Mandera, Anza and Rift Territory. Kenya had a total of 46 onshore and offshore exploration blocks across the country and off the coast and a total of 43 exploratory wells which have been drilled by 2015. A corresponding number of 41 licenses have been awarded to international oil exploration and production firms to carry out exploratory activities. Domestic crude oil deposits have been located in Turkana, in the northern part of Kenya bordering with Uganda. Extraction in Turkana may start in the near future. However because of no official information on the commercial supply of the domestic crude oil no conclusion can be drawn if the domestic crude will be available for power generation in the near future.

The consumption of petroleum products in the transport, power generation, industry and domestic sector have seen continuous growth with some declines seen in the periods of economic turmoil as illustrated in *Figure **12***. Total petroleum consumption in Kenya has grown from 40 thousand barrels per day in 1980 to 90 thousand barrels per day in 2013 and is projected to grow further as country’s GDP grows.

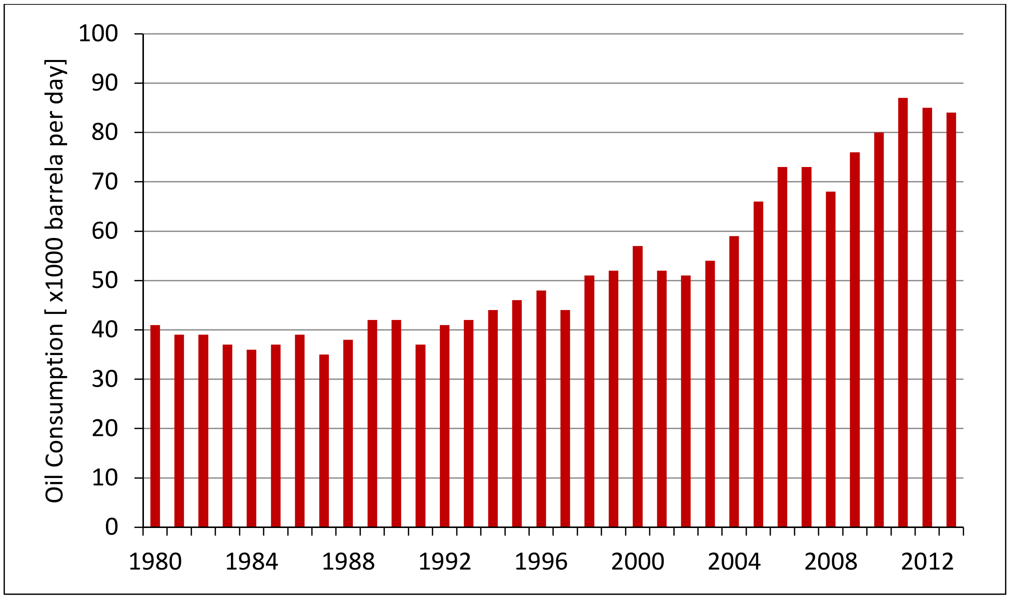

Figure 12 Oil consumption in Kenya. Data Source: (Energy Information Administration, n.d.)

The demand of different crude oil fractions (*Figure **13***) vary significantly. Light diesel oil fraction is seen to have the highest demand followed by fuel oil and motor gasoline. Aviation spirit, liquefied petroleum gas and heavy diesel oil fractions have the low demand.

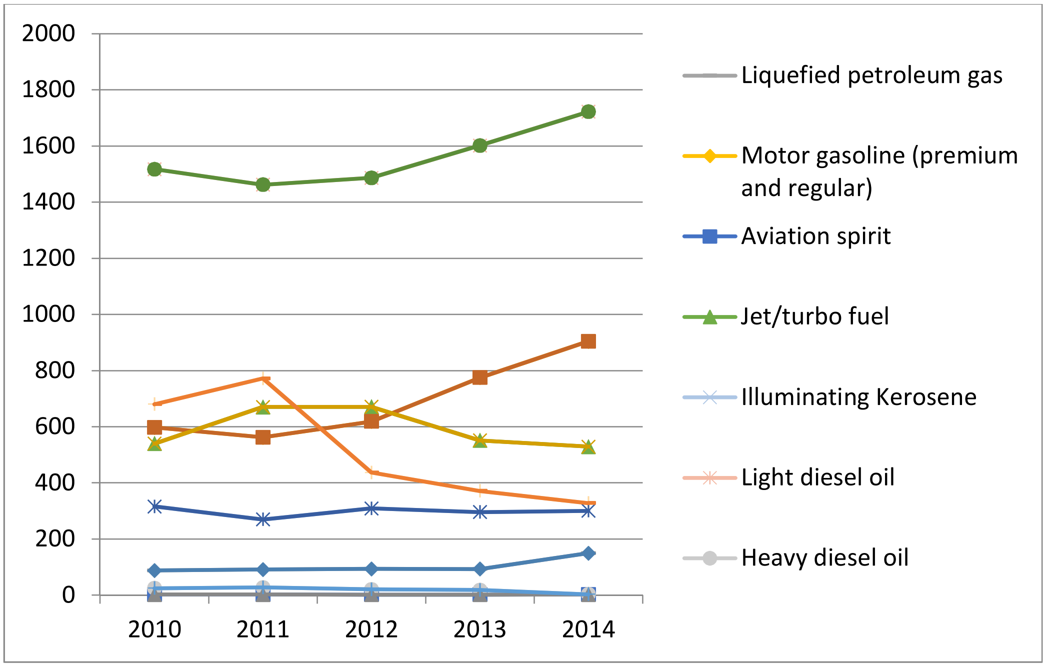

Figure 13 Demand of different fuels in Kenya. Source (Energy Regulatory Commission, 2015)

3.2.2 Natural Gas

Natural gas is a gaseous fossil fuel consisting of a mixture of hydrocarbons, primarily methane, extracted from geological formations beneath the earth's surface. It can be distinguished by its composition and by the extraction technology required by the geological formation. Beside the natural gas extracted from gas fields, called free gas that mainly consists of methane, there is also associated gas or flare gas. This gas is produced during the crude oil extraction process and is often flared. It generally shows a different composition than free gas. As relatively new gas types, unconventional gas resources are currently being developed such as shale gas or coal-bed methane trapped within shale and coal formations.

In the last several decades, natural gas has been the third important energy source in the world, behind crude oil and coal. The share of natural gas as an energy source for the world is growing in the recent years due to its rather environmentally friendly characteristics i.e virtually no sulphur content and low carbon di oxide emissions. Owing to the recent technological advancements in the extraction, supply and storage of natural gas and hence reduced costs an increased consumption of natural gas is foreseen. For these reasons, its already important role for electricity generation is further growing. However, the means of transport of natural gas are limited, i.e. in gaseous form in pipelines or as liquefied natural gas (LNG) in ships or trucks. These limitations restrict the use of natural gas to the vicinity of gas fields and an existing pipeline network with idle capacity; or it requires relatively high investment costs for constructing new pipelines or the transport in form of LNG.

3.2.3 Coal

Coal is a solid fuel commonly found as combustible black or brownish-black sedimentary rock with a high amount of carbon and hydrocarbons. Coal is classified as a nonrenewable energy source because it takes millions of years to form. Coal contains the energy stored by plants that lived hundreds of millions of years ago in swampy forests. The plants were covered by layers of dirt and rock over millions of years. The resulting pressure and heat turned the plants into the substance we call coal.

Coal has emerged as one of the important fossil fuel energy source in the last century and has served an important role in the industrial revolution. The cheap energy production from coal is made possible due to its natural abundance and relatively simply Rankine cycle which exploits this energy resource. However it comes with a number of disadvantages too. The pollution associated with the exploitation of coal has sparked an acute criticism on the use of this technology during the past decades, and has been termed as the leading cause of the global pollution warming problems.

As of now there is no operation power plant in Kenya utilizing coal as fuel. However the Kenya Vision 2030 developed by the Ministry of Energy and Petroleum, Government of Kenya has recognized its importance as the source of cheap energy and electricity and has advocated for the development of coal power stations in the near future.

Kenya avails of local coal reserves in the Mui Basin which runs across the Kitui county 200 km east of Nairobi. The coal basin stretches across an area of 500 square kilometers and is divided into four blocks: A (Zombe – Kabati), B (Itiku – Mutitu), C (Yoonye – Kateiko) and D (Isekele – Karunga). The Ministry of

Energy and Petroleum (MoEP) in charge of drilling appraisal wells discovered coal seams of substantial depth of up to 27 meters in the said basin. 400 million tons of coal reserves were confirmed in Block C. The MOEP has awarded the contract for mining of coal in Blocks C and D to the Chinese Fenxi Mining Industry Company. Coal mining has a strong environmental and social impact. The mining will require large scale resettlement measures which have not started yet. Further, mining itself will produce considerable pollution. Exploitation of Blocks A and B has been recently awarded to China's HCIG Energy Investment Company and Liketh Investments Kenya Ltd. Coal characteristics are of much lower quality import coal from South Africa with regard to content of energy, ash, moisture and sulphur.

Properties	Units	Value
Calorific Value	MJ/kg	18.0
Ash Content	%	37.0
Volatiles	%	25.0
Fixed Carbon	%	40.0
Moisture Content	%	8.0
Sulphur Content	%	2.4

Table 3 Properties of indigenous coal in Kenya. (Ministry of Energy and Petroleum, 2014)

3.3 Geothermal Energy

Geothermal energy is the heat from the Earth. It's clean and sustainable. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma. Below the earth's crust, there is a layer of hot and molten rock called magma. Heat is continually produced there, mostly from the decay of naturally radioactive materials such as uranium and potassium. The areas with the highest underground temperatures are in regions with active or geologically young volcanoes. These occur at plate boundaries or at places where the crust is thin enough to let the heat through.

Geothermal energy has been classified as a renewable energy resource because reinjection of water back in the well replenishes the resource.

Kenya is a country endowed with a massive geothermal potential from 8000 to 12000 MW concentrated mostly in the Rift valley and others in Homa Hills in Nyanza, Mwananyamala at the Coast and Nyambene Ridges. Within the Rift Valley geothermal resources are clustered in three regions namely the Central Rift estimated potential of 1,800MW, South Rift estimated potential of 2,450MW and North Rift estimated potential of 3,450MW (Government of the Republic of Kenya, 2011). The Government of Kenya recognizing the importance of the utilization if the geothermal energy resource established Geothermal Development Authority (GDA). GDA is tasked with developing steam fields and selling geothermal steam for electricity generation to KenGen and to private investors. The establishment of GDA has accelerated the establishment of new geothermal power plants.

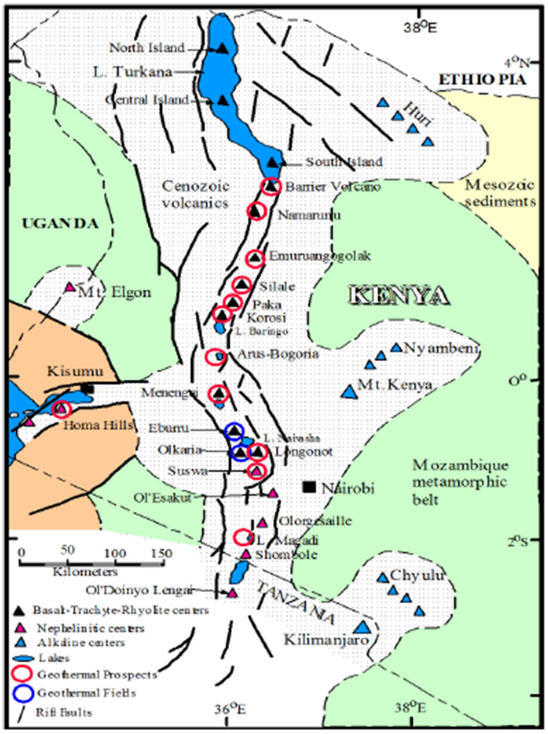

Figure 14 Location of Geothermal resource in Kenya. (Ministry of Energy and Petroleum, 2014)

Geothermal energy is a well-developed industry in Kenya. Projects have been implemented by both KenGen and large IPPs. Geothermal power is currently mainly being utilized in the Greater Olkaria Field located in the Hell's Gate National Park 120 km north-west of Nairobi. Today, the total geothermal capacity amounts to nearly 650 MW (Tab. 1, 2)-KenGen operates 513MW and 139MW of installed capacity by the IPP'S-. KenGen owned power plants are equipped with single flash steam technology while the plants owned by independent power producers (IPP) employs binary steam cycle technology. Due to the low short-run marginal costs, geo-thermal power plants generally run as base load.

However there are numerous challeges identified by ERC and GDA in the development of the Geothermal Power plants. Some of them are listed below:

1. Relatively long lead time of between 5-7 years from conception to production of electricity.

2. Geothermal projects typically progress through stages of reconnaissance, surface exploration, feasibility study, exploratory drilling, appraisal drilling, production drilling, steam field development and power plant construction stages which normally involve high upfront investment costs.

3. High resource development risks.

4. Inadequate geothermal expertise and expensive external technology.

5. Remote location, siting restrictions and long distances to existing load centers necessitating heavy investment in transmission and other support infrastructure.

6. Competing and conflicting interests in use of land and natural energy resources by various sectors of the economy.

7. Relocation and resettlement of affected persons during geothermal development.

3.4 Wind Energy

Wind energy is caused by solar energy and, in particular, by the non–uniform temperature distribution on earth (the same works for marine currents). About 0.2% of solar energy is converted in Wind energy and marine currents, which corresponds to about 350/400 TW globally.

Wind Energy is the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

The Wind Resource Assessment carried out by WinDForce shows that over 73% of the total area of the country experiences annual mean wind-speeds more than 6 m/s at 100 m above ground (Federal Ministry for Economic affairs and Energy - Germany, 2015). This fact establishes the immense potential for wind energy utilization in this country. The wind regimes in many parts of Kenya especially the northern and eastern regions such as Marsabit, Ngong and the Coastal region can support large scale utility electricity generation as these regions enjoy extremely good annual mean wind speeds in the range of 6-10 m/s throughout the year.

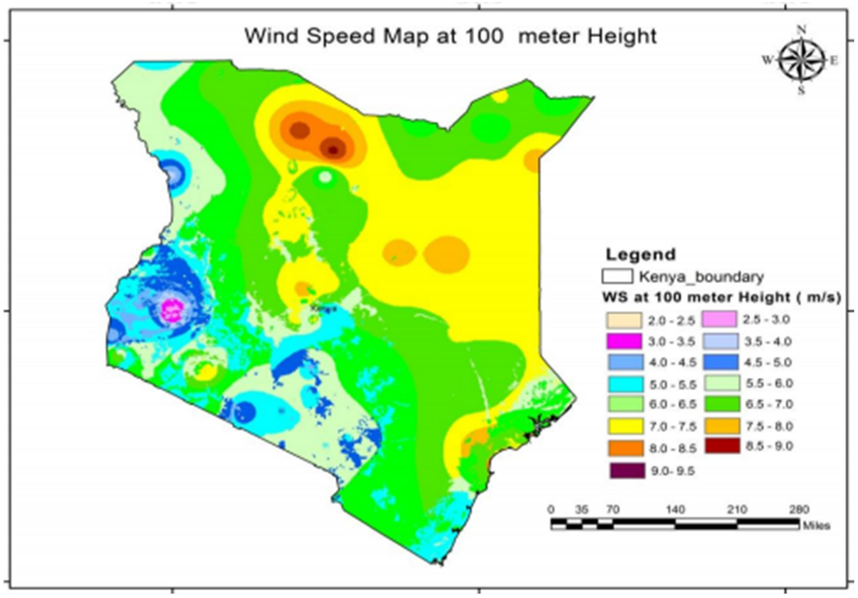

Figure 15 Wind Speed at 100m height in Kenya. Source: (Federal Ministry for Economic affairs and Energy - Germany, 2015)

Despite the immense potential that it holds, Kenya's wind energy sector had been confined to small projects focused on water pumping and grain milling in remote areas without grid connection. But efforts by the government to encourage investment in the sector are starting to pay off. The National

Wind Atlas created by the Kenyan Government is attracting investors interested in harnessing wind energy. The wind market is slowly gaining acceptance with local and foreign investors, the government, and NGOs which are taking active steps towards grid connected power generation. Kenya Electricity Generating Company (KenGen) commissioned a 5 MW wind farm in Ngong Hills in 2010 with further wind farms considered to be established in the near future.

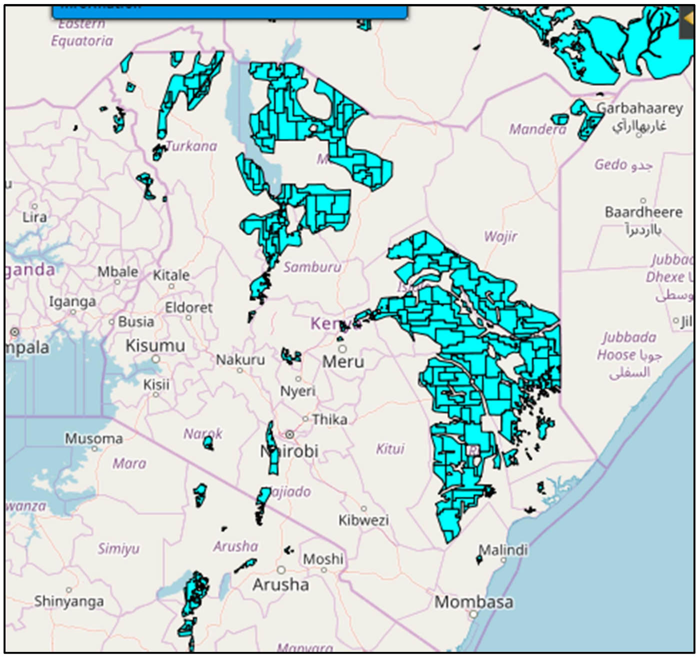

Figure 16 Identified sites for wind farms in Kenya. Source IRENA: Global Atlas, Map data

The exploitable wind energy sites in Kenya face several challenges the ones identified in Kenya's Wind Energy Market (Kirai & Shah, n.d.) are as follows:

1. Site selection: Wind potential assessments are site specific and time consuming. This means that wind energy development requires large initial investment for careful wind prospecting.
2. Good equipment and quality work is needed, both being cost-intensive.
3. Updated wind resource map for Kenya: The Ministry of Energy (MoE) has made some progress in this area. Suppliers of wind turbines often have to rely on meteorological data and customers' observations to determine whether a project site is viable. Such information is misleading and could lead to installation of poorly performing or non-performing systems.
4. Low awareness: Most owners of wind systems have had some previous experience or knowledge and the majority of wind turbine installations are done by the user. Apart from these first movers, there is generally low public awareness for wind energy.
5. Distance from transmission lines: Areas in the North that have the highest potential for wind energy generation are far from existent transmission lines, making grid connection expensive.
6. Local capacities: Technical local capacities for grid integration and system management are poorly developed due to the early stage of the market development for grid-connected systems.

Activities for capacity development are necessary.

3.5 Solar Energy

Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available. Modern technology can harness this energy for a variety of uses, including generating electricity, providing light or a comfortable interior environment, and heating water for domestic, commercial, or industrial use. There are several ways to harness solar energy: photo-voltaic, solar heating & cooling, and concentrating solar power which is typically built at utility-scale.

3.5.1 Solar Photovoltaic Technology

Photovoltaic (PV) materials and devices convert sunlight into electrical energy. A single PV device is known as a cell. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. To boost the power output of PV cells, they are connected together in chains to form larger units known as modules or panels. Modules can be used individually, or several can be connected to form arrays. One or more arrays are then connected to the electrical grid as part of a complete PV system. Because of this modular structure, PV systems can be built to meet almost any electric power need, small or large.

The geographical location of Kenya is across the equator due to which it receives high amounts of solar radiation throughout the year. The average daily radiation in more than 28,000km2 of land in Kenya is above 6 kWh/m²*d throughout the year, thus resulting in a continuously good and relatively stable potential for electricity generation from solar.

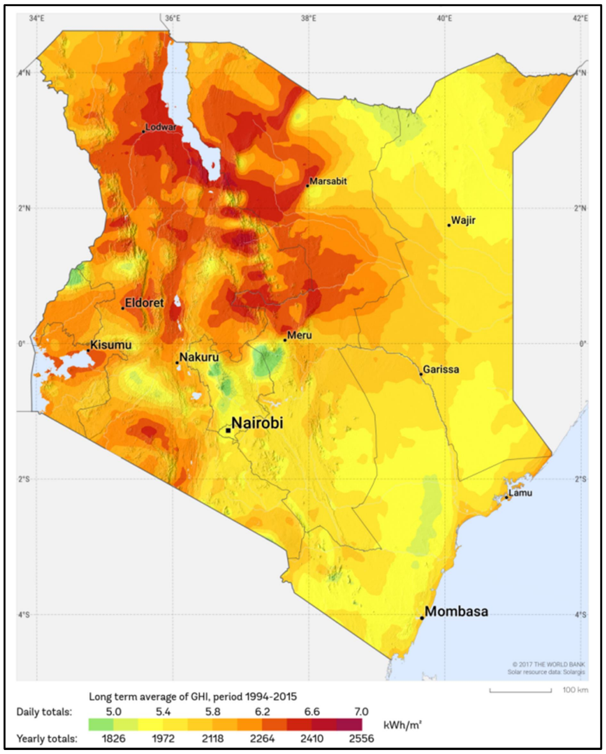

Figure 17 Solar Photovoltaic power potential (Global Horizontal Irradiation) in Kneya. Source: 2017 The World Bank, Solar resource data: Solargis.

The high Global Horizontal Irradiation is observed towards the North Western part of the country. Towards the southern and eastern side of the country comparing of coastal region including the Mombasa region an average yearly radiation of 2100 kWh/m^2 is observed as shown in the *Figure* ***17***. These regions are relatively densely populated compared to the Northern and the North Western regions. Hence the use of solar technology in these regions for power generation purposes is economically viable.

Kenya is well known for a large-scale market-driven penetration of very small photovoltaic (PV) systems in rural areas. It is estimated that about 200,000 rural households already use PV systems, and that the number is increasing rapidly (Government of the Republic of Kenya, 2011). Most of the PV systems employed have a capacity of 12-50W consisting of low-cost amorphous modules and lead acid batteries. Due to comparatively low costs, the use of PV in rural households is much more widespread in Kenya than in other African countries though some of them have special PV household electrification programs.

3.5.2 Concentrated Solar Power Technology

Concentrating Solar Power (CSP) technologies use mirrors to concentrate the sun's light energy and convert it into heat to create steam to drive a turbine that generates electrical power. The plants consist of two parts: one that collects solar energy and converts it to heat, and another that converts the heat energy to electricity. The advantage of CSP technology over the PV technology is that both the parts of the CSP system can be decoupled from each other hence giving the user possibility of thermal storage. The stored thermal energy can be used in times of high energy demand or when the solar radiation is unavailable. Various configurations for concentrated solar power applications are available today including Linear Fresnel and Solar tower configurations.

CSP generation requires direct normal irradiation (DNI) to operate (i.e. a direct angle of incidence at clear skies without clouds). The map in *Figure* ***18*** shows the solar direct normal irradiance in the various regions of the country. Kenya is endowed with very high solar resources and is one of the highest of Sub-Saharan African countries. Its solar direct normal irradiance is approximately 2,300 kWh/m^2/year in favorable regions (Lahmeyer International, 2016b). However, there are presently no operational CSP plants in Kenya.

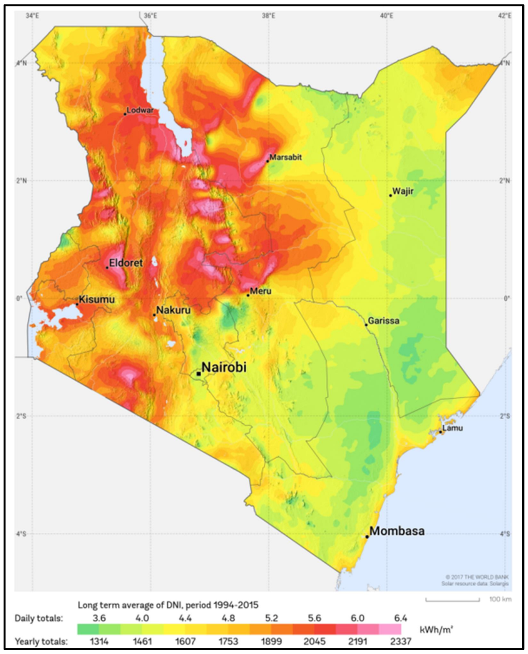

Figure 18 Concentrated Solar power potential (Direct Normal Irradiation) in Kneya. Source: 2017 The World Bank, Solar resource data: Solargis.

Due to currently rather unclear development prospects of CSP projects and the considerable amount of more economically viable renewable alternatives like geothermal and wind in Kenya, CSP is not addressed in the medium and long term expansion planning developed by the Ministry of Energy and Petroleum. However, in the future the development in the CSP technology might offset the economic viability and hence the policy.

The challenges faced in harnessing the solar power as identified in the National Energy policy are the following:

1. Disjointed approach in policy implementation and promotion of solar energy projects in the country.

2. The percentage of solar energy harnessed for commercial and domestic applications is insignificant relative to the potential.

3. Prohibitive costs of solar home systems despite favorable fiscal incentives and arising from lack of appropriate credit and financing mechanisms.

4. Erosion of consumer confidence because of inappropriate system standards, faulty installations, importation of sub-standard systems and poor after sales service.

5. Rampant theft of solar photovoltaic panels, which discourages their installation.

6. Lack of awareness on the potential, opportunities and economic benefits offered by solar technologies.

3.6 Biomass/Biogas

There are many different types of biomass which can be employed for power production through a number of different processes and technologies. The complexity of the biomass in terms of C/N ratio is the first parameter to be considered, the more complex the system, the more difficult is to extract the energy content, therefore combustion processes are adopted. The other parameter is the moisture content: the higher the moisture content, the lower is the combustion efficiency.

Type of conversion process	C/N	Moisture	Type of process	Products
Bio-chemical	<30	>30%	Fermentation Anaerobic dig. Aerobic dig.	Bio-Ethanol Biogas Heat
Thermochemical	>30	<30%	Combustion Gasification Pyrolisis	Heat Syngas Pyrolisis gas
Physical-chemical	-	-	Oil extraction Transesterification Compaction	Oil Biodiesel Pellets

Table 4 Biomass Conversin Processes and Products

Biomass is organic material that comes from plants and animals, and it is a renewable source of energy. Biomass contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels.

Biomass is a biological material derived from living, or recently living organisms. Biomass is considered a renewable energy resource, when the utilization rate is equal to or lowers than the capacity of production i.e. biological capacity of renewal. The energy exploitation of renewable biomass is a CO2-neutral (or almost neutral) process.

Solid biomass, rich in lignin can be used in an incinerator where the produced flue gas provides heat and electricity or in a gasification process to provide a syngas for further use. Solid/liquid bio-mass, which is poor in lignin, is commonly used in fermenters and with the produced biogas also heat and electricity can be provided for further use.

Biogas is a mixture of methane and carbon dioxide with small amounts of other gases and needs a further cleaning step before it is usable. Biogas is similar to landfill gas, which is produced by the anaerobic decomposition of organic material in landfill sites.

Municipal Solid Wastes (MSW) constitutes a potential source of material and energy as well. Be-cause of it heterogeneous components, it is necessary to pre-treat this wastes before it can be used. The objective is to recycle as much as possible and use the remaining material with a high calorific value in an incinerator or gasification process to provide heat, electricity or syngas. The wet material can be used in a fermentation process to produce bio-gas.

Biomass energy provides 68% of Kenya's national energy requirements and it is expected to remain the main source of energy for the foreseeable future. Most of the biomass use is for cooking purposes and heating purposes in summers. In 2000, Kenya was reported to use 34.3 million tons of biomass for fuel of which 15.1 million tons was in form of fuel wood while 16.5 million tons was wood for charcoal processed in kilns with only 10% efficiency. Up to 43% of the national consumption was from sustainable supplies while 57% was from unsustainable supplies (Mugo & Gathui, 2010) The use of biomass for power production purposes is still not explored widely.

There exists substantial potential for power generation using biomass resources such as animal waste for agro based industries, bagasse by the sugar industry in a process called cogeneration and municipal waste by the local authorities for own consumption and export to the grid. As of 2017 there are two power plants Muimas Sugar Company and Biojoule Kenya with installed capacity of 26 MW and 2 MW respectively as listed in *Table **2***.

The challenges faced in the development of Biogas/Biomass power plants as identified in the National Energy Policy (Ministry of Energy and Petroleum, 2014) are listed below:

1. Lack of legal, regulatory and institutional framework for exploitation.

2. Inadequate data and information on potential of municipal waste.

1. Use of obsolete, inefficient plant and equipment in the cogeneration industry.

2. Lack of a reliable and continuous supply of biomass.

3. Limited technical, human and financial resources for cogeneration development.

4. Inadequate technical capacity in commercial and emerging cogeneration technologies.

5. Lack of awareness in cogeneration potential in areas where the agro-wastes are available.

6. Inadequate data and documented assessment of resources and potential.

7. Lack of model Power Purchase Agreement (PPA) for cogenerated power in the country.

3.7 Nuclear Energy

Nuclear technology uses the energy released by splitting the atoms of certain elements. The heat is then used in steam turbines to produce electricity in a nuclear power plant.

The global energy landscape is changing driven by technology improvements and environmental concerns. As of now 35 countries are operating their nuclear reactors and more than forty countries are considering developing nuclear power (Hu, 2017).

During the recent years the technology improvement and stringent international safety requirements has made Nuclear energy relatively more reliable and safe. While hydro power is susceptible to weather and climatic changes, Nuclear power can provide the base load capacity throughout the year. Considering also that Nuclear energy has no CO2, NOx or Sox emissions, it is friendlier to the environment than coal or other fossil fuel based technologies. However the issue of nuclear waste disposal and its implications on the environment cannot be overlooked.

Today China is leading the way towards development of Nuclear energy with its 37 Nuclear power plants (providing 32 GW) in operation and further 20 under construction.

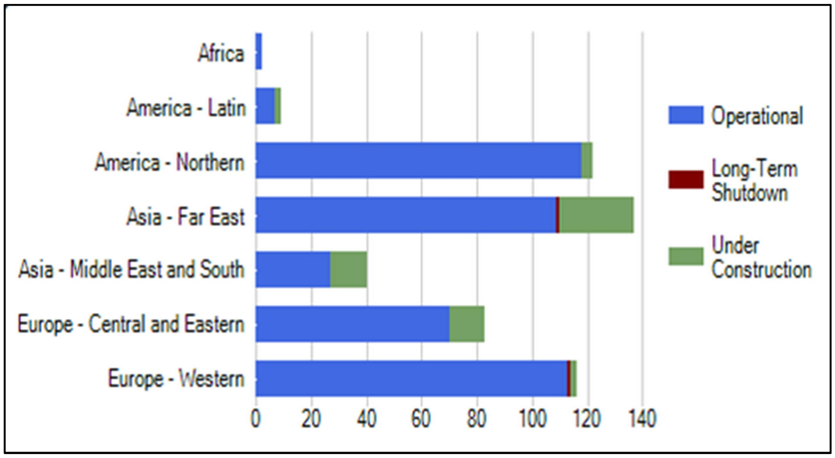

Figure 19 Number of Nuclear power reactors in different regions of the world.

South Africa is the only country in Africa with a commercial nuclear power programme. Ghana and Nigeria have employed Miniature Neutron Source Reactor (MNSR)

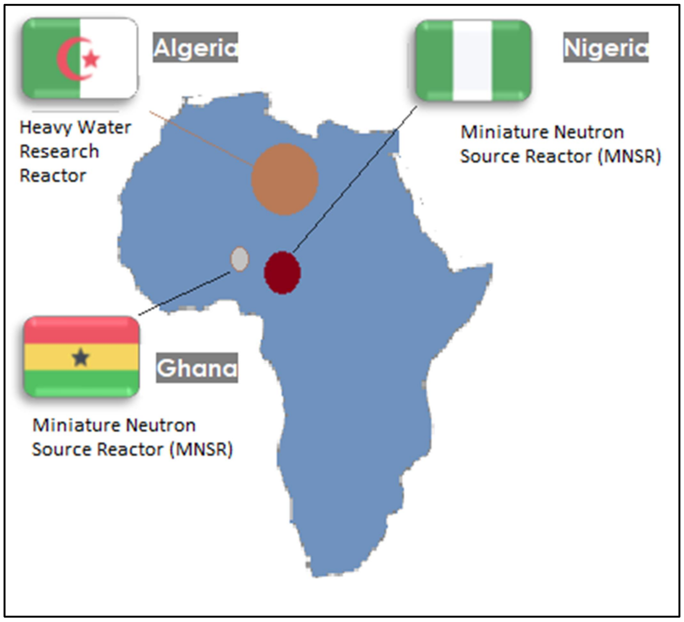

Figure 20 Nuclear Power Reactors in Africa.

Nuclear energy has low fuel costs compared to coal, oil and gas-fired plants. Uranium, however, has to be processed, enriched and fabricated into fuel elements, and about half of the cost is due to enrichment and fabrication. The World Nuclear Association cites prices of about US$2,555 per kilogram of uranium as UO2 reactor fuel which works out to a fuel cost of US c 0.71 /kWh (Government of the Republic of Kenya, 2011).

There is little available resource of nuclear fuel in found in Kenya. At present, only low levels of uranium oxide have been discovered. However, exploration of uranium is still on-going. (Lahmeyer International, 2016b)

4 HISTORY OF ENERGY MODELING OF KENYA

Different energy modeling tools and techniques have been employed by the government and academic institutions to model the energy sector of Kenya. A brief overview of the published reports is presented in this section. This work tries to fulfill the existing gaps of the most recent and relevant papers and reports which are analyzed in the following paragraphs. Each report analyzed on the basis of its modeling strategy, results and gaps are presented.

4.1 Least Cost Power Development Programme- Kenya Vision 2030

This study is an update of the Least Cost Power Development Plan that was finalized in March 2010. The update involved review of the load forecast in light of changed pertinent parameters, commissioning dates for committed projects, hydro data, costs of generating plants and transmission system requirements for the Least Cost Power Development Plan. The study incorporates key lessons learnt in the last update mainly the need to incorporate population, urbanization and efficiency gains and technology in undertaking the demand forecast and capturing of potential new demand arising from the vision 2030 flagship projects and other investor projects. The study is completed with the aid of several models: excel for load forecasting, VALORAGUA for hydro-thermal system optimization, WASP for the system expansion plan optimization and PSSE for transmission planning.

The report analyzes three demand forecasts scenarios (Reference, Low, High), in line with the GDP growth rate, population growth and urbanization rate and electrification rate projections.

The study found that Hydro, Medium Speed Diesel (MSD), and Gas Turbines (GTs) are suitable for peaking capacity. Nuclear, Geothermal, Wind and Coal are suitable for base load operation. Imports are suitable for both base load and peaking. The optimal development program as concluded in this study is dominated by geothermal, nuclear and coal power plants.

Identified Gaps:

The load forecast done for this study highly overestimated the demand for energy in Kenya. The resulting analysis of scenarios based on the overestimated load forecast is deemed misleading. This study does not include the quantitative analysis of CO_2 emissions from the power plants. Considering that environmental impact of power generation activities and clean power production has become increasingly important in twenty-first century the emission accounting from the power generation activities cannot be overlooked.

4.2 EAPP Regional Power System Master Plan

The objective of this study was to identify and quantify the potential benefits of regional cooperation in terms of transmission and generation within the East Africa Power Pool member countries. It undertakes the modeling of the power systems of the EAPP member countries based on the concept of 'least-cost development planning'.

The BALMOREL model was used to simulate the scenarios of the EAPP Master Plan. The model area includes all of the EAPP member countries namely Burundi, Djibouti, DRC, Egypt, Ethiopia, Kenya, Libya, Rwanda, Sudan, South Sudan, Tanzania and Uganda. A number of scenarios were set up in order to illustrate the economic consequences of different possible future strategies.

The Leveled cost of electricity (LCOE) was calculated for different technologies depending on the realized full load hours. The analysis showed that Gas Turbines are suitable for peak load generation while hydro and geothermal are suitable for base load power generation as their LCOE reduces sharply be increasing the number of full load hours. This study provides analysis of all possible new interconnectors in the EAPP region and assumptions regarding their type, length and capital costs.

Identified Gaps:

While the report provides a relatively good overview of the feasibility of interconnections the analysis of competitive power generation technologies is not provided. A narrow range of technologies are available to choose from and off grid technologies are not considered for independent power generation.

The investment policies of the individual countries are not taken into account in this study. For the individual countries, policy and investment decisions necessitate more detailed and complex planning.

4.3 Electrification pathways for Kenya

This study analyzed low and high demand scenarios, selected implications and investigated pathways that would allow the country to reach its electrification targets by 2030. Two modeling tools were used for this study, namely OnSSET and OSeMOSYS. The soft-link between these tools was done in order to capture both the spatial and temporal dynamics of their nature.

The results showed that geothermal, coal, hydro and natural gas would contribute to the optimal energy mix for the centralized national grid. However, in the case of the low demand scenario a high penetration of stand-alone systems is forecasted. The high demand scenario leads to a shift in the optimal technology mix, with a higher penetration of mini-grid technologies and grid extension.

Identified Gaps:

The study develops a soft link between OnSSET and OSeMOSYS. The significant limitation is the time resolution in OnSSET which assumes overnight electrification. Linking OnSSET with OSeMOSYS, which is a multiyear tool, can be misleading. To be able to add a multiyear analysis to OnSSET however it would require information about the priority areas for electrification. This can differ from country to country depending on policies and national plans. It would also help better reflect logistical realities. Feed-in tariffs are not included in the analysis.

4.4 Development of Power Generation & Transmission Master Plan, Kenya

This report provides the respective Long Term Plan (LTP) for the period 2015 (base year) to 2035. This LTP is the identification and analysis of suitable expansion paths of the Kenyan power system for that period, complying with the defined planning criteria and framework. This encompasses:

- Analysis of past electricity demand and development of future demand scenarios,

- Analysis of suitable expansion candidate fuels and technologies, their optimal sizing, siting and scheduling,
- Modeling of their expected contribution to the future power generation and the probable operation of the generation system,
- Modeling of the transmission grid for the year 2030 and the analysis of its performance under several criteria,
- Investment analysis summarizing financial implications of the expansion plans on the future investment needs and their expected schedule.

The study analyzes three scenarios of electricity demand growth namely Reference scenario, Vision scenario and Low scenario and one sub-scenario called Energy Efficiency which is developed applying the energy efficiency potential to the reference scenario.

Several important results are highlighted in this study. For base load geothermal power plants are ranked best in terms of generation costs, followed by bagasse power plant (biomass cogeneration) and the HVDC (high voltage direct current) interconnection with Ethiopia. Nuclear power plants show the highest costs for all base load plants. For intermediate load plants coal power plants are cheaper than gas fuelled CCGT plants (domestic gas and LNG). For lower capacity factors (e.g. 50%) the NG-CCGT candidate appears to be the preferred option assuming that the domestic gas is available. For peaking units hydropower plants are the preferred option. The alternatives are gasoil fuelled gas turbine and HFO fuelled MSD but at much higher generation costs though easier to develop.

Identified Gaps

5 MODEL SPECIFICATIONS

The model used to calculate results presented in this report is based on the Open Source Energy Modeling System (OSeMOSYS), a tool designed to inform the development of local, national and multi-regional energy strategies (Nandi Moksnes, Manuel Welsch, Francesco Gardumi, Abhishek Shivakumar, Oliver Broad, Mark Howells, Constantinos Taliotis, 2015). The motivation behind the use of OSeMOSYS instead of more commonly used MARKAL and TIMES is that the code is relatively straightforward, elegant and transparent and can be tailored to the specific problem at hand.

A brief overview of OSeMOSYS is provided below.

5.1 OSeMOSYS

The model is driven by exogenously defined demands for energy services. These can be met through a range of technologies which exploit a set of resources, defined by their potentials and costs. The policy scenarios may impose certain techno-economic constraints and pollutant emission limits. It is a deterministic linear optimization model and minimizes the total discounted costs. Furthermore, policy scenarios may impose certain technical constraints, economic constraints or environmental targets. OSeMOSYS consists of various functionality blocks as depicted in the *Figure* ***21***.

The OSeMOSYS model is disaggregated into several functional components referred to as 'blocks' (Howells et al., 2011). To develop the energy model for Kenya, OSeMOSYS is divided into six functional blocks as illustrated in *Figure* ***21***. The model calculates the optimal flows of energy carriers that play in the production sector, converted through a network of transformation technologies to supply the demand in order to meet set objectives. To achieve this, the model differentiates between 'Fuels' and 'Technologies'. Energy carriers and services are designated as 'Fuels'. Each Fuel represents a specific energy carrier or a group of similar energy carriers. Additionally, fuels are produced, transformed and used by technologies. The 'technologies' represent; energy producing, energy transforming and energy consuming systems. The reference energy system of the model is illustrated in Appendix D.

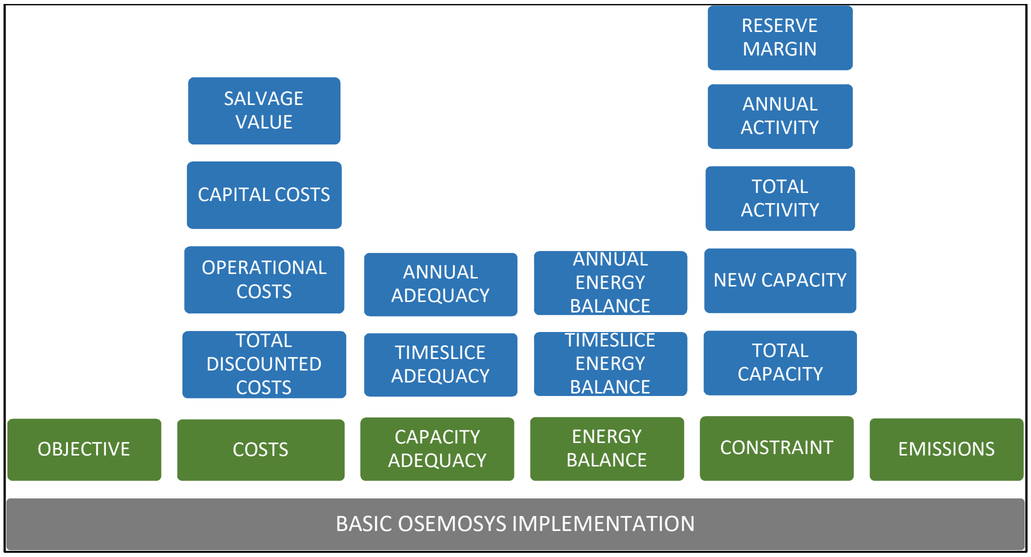

Figure 21 Functionality blocks of OSeMOSYS. Source: Own illustration based on (Konstantin Löffler, Karlo Hainsch, Thorsten Burandt & Claudia Kemfert, 2017)

At the heart of the code is the objective which in most of the cases unless otherwise specified is the minimization of the total discounted costs. The second functionality block comprises of the costs in this block the costs associated with the development, use and maintenance of the technology are defined. The third block defines the adequacy of installed capacity to meet the peak demand and ensures that the specified peak demand in each time period as well as over the whole modeling period is satisfied. The fourth block is the Energy Balance which ensures that the energy production in each of the time slice and over the whole modeling period is met. The fifth block defines the constraints of each of the technology which include constraints of the power generation

The OSeMOSYS open source nature has made ease of use possible and allows modifying the code according to the need.

Various other energy modeling softwares are available today. One of the most important of them is MARKAL which is developed by the International Energy Agency (IEA). The other one worth mentioning is TIMES which combines a technical engineering with an economical approach, thus merging the characteristics of both (Konstantin Löffler, Karlo Hainsch, Thorsten Burandt & Claudia Kemfert, 2017).

5.2 Previous Studies Based on OSeMOSYS

OSeMOSYS has been used in a variety of research to provide insights about regional energy systems and their transition towards renewable energies. It has been employed to develop global, regional and country specific energy models. Löffler et al., 2017 implemented OSeMOSYS to analyze the paths towards a global supply of renewable energy by 2050. Moura et al., 2015 implemented a version called SAMBA where the South American energy system is depicted. Recently, (Vigone et al., 2017) modeled the Tanzanian power system, analyzing four different scenarios of electricity demand, prices, loads and costs getting and performing the sensitivity analysis to check the various parameters affecting the technology development.

5.3 Definition of Scenarios

Two scenarios are considered for the analysis, Government of Kenya (GoK) Policies Scenario and New Policies Scenario. GoK policies scenario follows the Kenyan government policies for development of the electricity sector as described in recently published reports such as Vision 2030 (Government of the Republic of Kenya, 2011) ‘Development of Power Generation and Transmission Master Plan , Kenya Medium term Plan 2015-2030 (Lahmeyer International, 2016a) & National Energy Policy (Ministry of Energy and Petroleum, 2014) projections. New Policies scenario is defined based on the demand projections by International Energy Agency (International Energy Agency, 2014) taking into account the Decarbonization goals and UN SDG-7 which ensures access to affordable, reliable, sustainable and modern energy for all.

5.3.1 GoK Policies Scenario

Demand for electricity is expected to grow considerably for GoK Policies scenario, as the connectivity and specific consumption increases. The objective of the demand forecast is to provide a sound basis for the power system expansion planning. The electricity demand forecasts carried out for Kenya regularly overestimated demand when compared to actual demand growth in medium term period. They also exceeded by far the forecasted growth rates for similar African countries. The demand forecast for GoK policies scenario, presented in *Figure 22* is very much realistic and takes into account the wide range of largely ambitious government plans and less challenged flagship project developments (Lahmeyer International, 2016b). To extrapolate the data the forecasts have been linearly adjusted from their corresponding previous year (2035) projections to exhibit a 9% annual demand growth rate towards 2040.

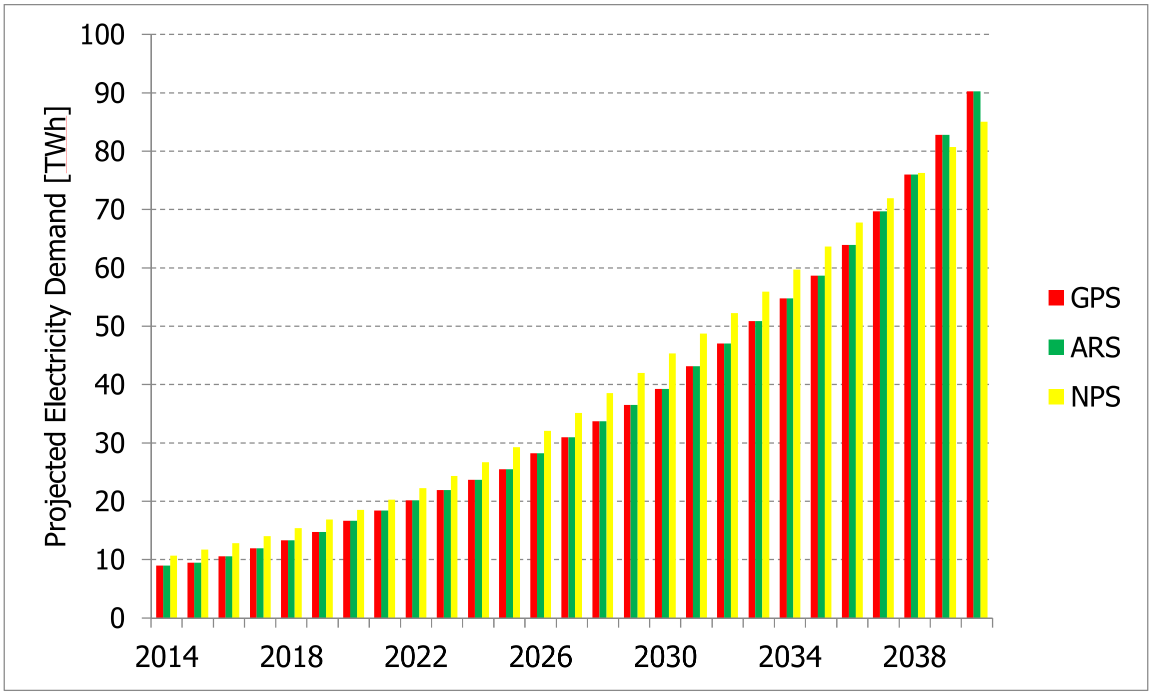

Figure 22 Electricity Demand Growth (TWh) in Two Scenarios.

The current energy mix for Kenya has a large share of renewable energy technologies. The energy production during the period 2014 to 2017 has been dominated by renewables which mainly comprise of hydro and geothermal power generation technologies. The renewable technologies account for more than 64% of the total installed capacity. In the OSeMOSYS model the amount of renewable energy technologies is determined by given residual capacities for the modeling period 2014 to 2017. For the period 2017 to 2040 a renewable energy share minimum of 50% of the total energy production is considered for “GoK policies scenario”.

Investment restrictions are introduced for the period of 2014 to 2017 to model Kenyan electricity sector as accurately as possible. The available generation capacity during this period leaves largely unsatisfied the total demand for electricity in the country.

The investment plans of government in Nuclear energy are also taken into consideration. A 4,000 MW of Nuclear energy power plant investment is considered during the modeling period. The first nuclear plant of 1,000MW is expected to be commissioned in 2022. Additional units of 1,000MW each are expected to be commissioned in 2026, 2029 and 2031 (East Africa Power Pool, 2014). Moreover the government’s intention to develop geothermal power generation capacities is also taken into account.

5.3.2 New Policies Scenario

In this scenario, the growth of Kenya’s national economy is assumed to boost electricity demand in industries while at the same time efficient use of energy is considered. Electricity demand rises due to; increase in population, per capita consumption, the increase in electrification rate and consistent economic growth.

The annual electricity demand growth rate of 9.6% (International Energy Agency, 2014) is considered until 2030, which reduces to below 6% towards 2040 as the country’s population growth rate reduces and less number of new connections are added. Electricity access improves in both urban and rural areas in the New Policies Scenario, but urban electrification rates continue to be higher and, on average, business and households in urban areas consume more electricity. By the end of the modeling period 100% electrification rate is assumed for the population in urban areas while for the population in rural areas an electrification rate of 75% is assumed.

The share of renewables in the new policy scenario is considered to be a minimum of 44% in 2040. No investment restrictions are applied to the model and the political intentions of government to invest in a particular technology are ignored in this scenario.

5.3.3 100% Renewable Scenario

This scenario assumes the same demand profile for electricity as for GoK policies scenario. The target of energy production from 100% renewable energy sources is set by 2030. Renewable energy sources such as geothermal and hydro are found in huge abundance in Kenya. Also different types of solar PV, Concentrated solar power (CSP), Wind turbines and power production using biomass as fuel are considered compete for power production in this scenario. The only direct CO2 emissions in this scenario are from biomass utilization. Biomass is considered carbon neutral even if CO2 emissions arise from its burning. So no CO2 emissions are analyzed for this scenario.

5.4 General Model Parameters

5.4.1 Regional Disaggregation & Modeling Period

The whole country of Kenya is modeled as a single region. As earlier mentioned, this paper does not consider trade of electricity between Kenya and neighboring countries, and the modeling period considered falls between 2014 and 2040.

5.4.2 Fuels & Technologies Disaggregation

Fuels are the energy carriers which have a specified demand and have to be met by the model. The technologies consume and produce fuels. Conventional fuels (Table.A2. Appendix A) used in power plants-Diesel, Natural gas, Coal etc.- as well as the electricity produced by the power plants is considered as fuel.

The technologies both use and produce energy. The power plants (technologies) are considered to be energy transformers. The extraction or import of fuels is also modeled as technologies. This model considers twenty six different power generation technologies including the fossil fuel based power plants, nuclear power plants, renewable technologies & independent power generation technologies as listed in Table.A1 Appendix A

5.4.3 Time Disaggregation

While OSeMOSYS uses most data on an annual basis, it also offers a much more detailed approach with respect to time periods and time dependent data (Konstantin Löffler, Karlo Hainsch, Thorsten Burandt & Claudia Kemfert, 2017). A year is divided into several "time slices" in order to take into account variation of demand during certain time periods on a daily or monthly basis.

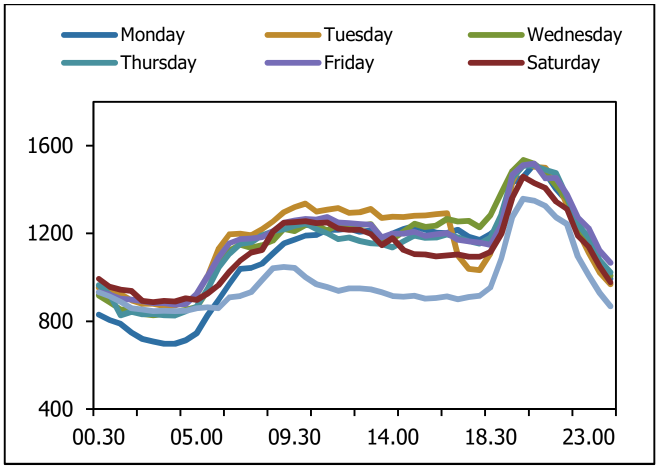

Figure 23 Daily average national generation demand (MW) for 2016. (Kenya Power & Lighting Company Ltd., 2017)

The daily generation demand for Kenya is almost constant during the daytime, reaches its peak during the evening hours and is lowest in the night as illustrated in *Figure 23*. Accordingly a day is divided into three time slices, 12 hours day time, 8 hours night time and 4 hours peak time.

Seasonal changes do not have a significant effect on the generation demand during the whole year; however the generation demand varies on a monthly basis and has a growing trend mainly due to continuing increase in the electrification rates of Kenya. Hence the year is divided into twelve time slices, with each month weighted on the basis of actual number of days within that month. In total each year of the modeling period is divided into 36 time-slices (12 months and 3 per day).

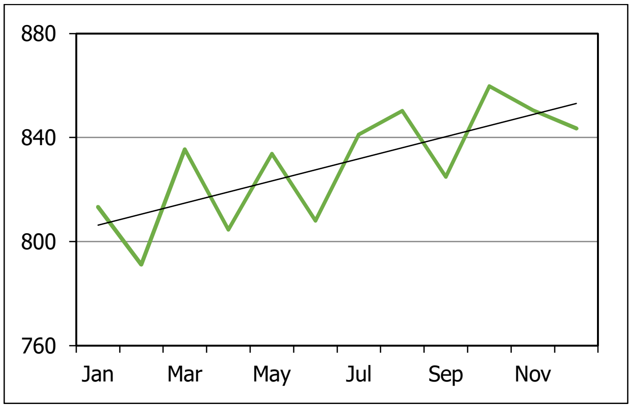

Figure 24 Monthly average national generation demand (MW) for 2016. (Kenya Power & Lighting Company Ltd., 2017)

5.4.4 Reserve Margin

Reserve margin is the excess operational capacity installed over and above the peak demand requirement. The reserve margin is introduced in order to increase the system robustness and make it more reliable. In OSeMOSYS the reserve margin of 18% is introduced for all scenarios. The technologies available to choose from to provide the reserve margin are thermal (NG-CC, NG-OC, HFO) and nuclear power plants.

5.5 Technical Parameters

5.5.1 Residual Capacity

The capacity degradation, lifetime and the retirement schedule of the installed capacities are taken into account in the residual capacity parameter. Total installed capacity in Kenya was 2258 MW in 2017. At the end of the modeling period 737 MW of the previously installed capacity is still available after 2040.

Wind turbines are found to lose 1.6 ± 0.2% of their output per year, with average load factors declining from 28.5% when new to 21% at age 19. This trend is consistent for different generations of turbine design and individual wind farms. This level of degradation reduces a wind farm's output by 12% over a twenty year lifetime (Staffell & Green, 2014). The general rule of thumb used in the industry for technology degradation of solar-PV panels is 1% degradation per year. Considering that the solar-PV has a life span of 20 years we can estimate a 20% capacity degradation of solar in its life time.

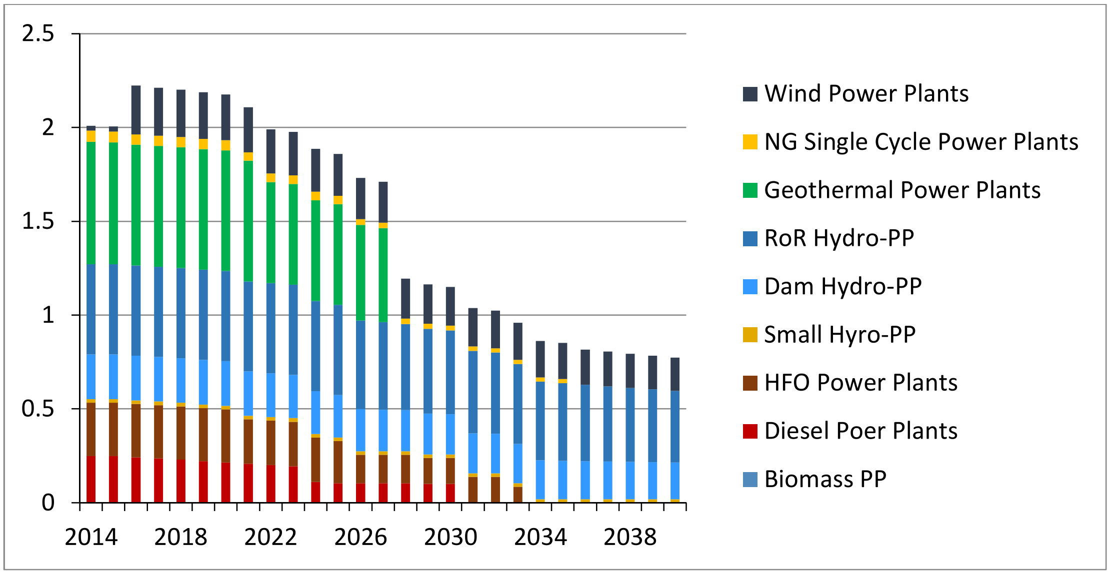

Figure 25 Residual Capacity of power installed power plants during 2014-2040

5.5.2 Operational Life

The operational life of the power plant measures the time in years the power plant is producing electricity after being commissioned. The operational life varies for each technology. There are efforts being made to increase the operational life of different technologies with various studies underway. It has been observed in some cases the power plants are operated beyond their design life by employing proper management, vigilance and safety enhancements. However for the purpose of this research, definition of operational life of a power plant is based on design life investigated for each technology. The operational life of dam hydro power plant is 50 years while for RoR and small hydro the lifetime is 30years

Description	**Operational Life (years)**
Biomass CHP plant	30
Coal power plant	35
Diesel power plants off grid	10
Diesel power plants (Utility)	20
Geothermal power plant	25
Oil fired gas turbine OIL SCGT	25
Small hydro power plant (SHP)	30
Dam hydro power plant	50
Run-of-river hydro power plant	30
Natural gas (Combined Cycle)	30
Natural gas (Single Cycle)	25
CSP	25
Solar PV	20

Wind (Onshore, 30% CF)	25
Nuclear Technology	60

Table 5 Operational life of various power generation technologies

5.5.3 Technology Efficiencies

The efficiencies of technologies are expressed through Input Activity and Output Activity Ratios. The efficiency of a technology is the ratio of the output to the input and accounts for the losses. Technologies which do not have a cost intensive utilization of fuel are considered to be 100% efficient. For instance solar and wind technologies don't use fuel to produce electricity hence in OSeMOSYS they are considered to be 100% efficient. The technology efficiencies of technologies (production, transmission and distribution) are listed in Table C3 Appendix C.

5.5.4 Capacity Factor

The net capacity factor of a power plant is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time. Capacity factor indicates the maximum time a technology may run in a given time-slice. The capacity factor is defined for each technology in every time-slice. Certain technologies (diesel, coal, geothermal) have the same capacity factor over the complete time slices but most of the renewable technologies especially hydro, wind and solar have a highly variable capacity factor susceptible to seasonal and weather changes. A complete list of capacity factors for each considered technology is mentioned in Table C3 Appendix C.

5.5.5 Availability Factor

The availability factor of a technology is the amount of time that it is able to operate over a certain period, divided by the amount of the time in the period. It includes the time periods where only partial capacity is available. The time period considered for the calculation of availability factor is one year. So for our purpose the fraction of a year the technology is available will be included in the availability factor. The availability factors of the considered technologies are listed in Table C3 Appendix C.

5.6 Economic Parameters

5.6.1 Fuel Price Projections

(a) Crude Oil & Natural Gas

In real terms, crude oil prices in 2016 were at their lowest levels since 2004, and natural gas prices were the lowest since prior to 1990 (US Department of Energy, 2017). Both prices are projected to increase over the projection period (*Figure **26***). However as the world is reducing its dependence on oil we also examine the situation in which the prices of crude are lower than projected ones.

Natural Gas prices are highly dependent on the domestic resource availability and technology. The price of Natural gas considered for Combined Cycle gas turbine ranges between 30-45 $/MWh while for Open Cycle Gas Turbine the price range is much higher and ranges between 45-70 $/MWh (IEA ETSAP, 2010). Considering that Kenya by far has little discovered natural gas reserves we also examine the implication of higher NG prices than projected ones.

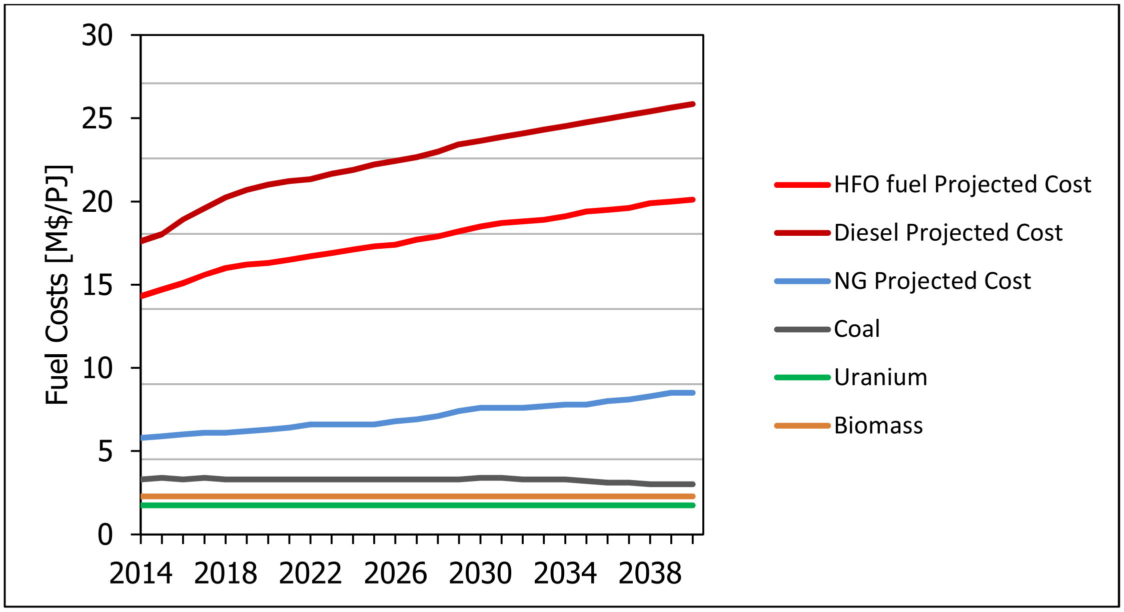

Figure 26 Fuel price projections and possible variations. ((US Department of Energy, 2017)*)*

(b) Biomass

The fuel for Biomass CHP plant price ranges between 30 to 50 $/MWh in IEA member countries (IEA ETSAP, n.d.-a). Considering that Kenya is the country rich in biomass resources as mentioned in chapter 3, a lower price (15$/MWh) of biomass is considered.

(c) Uranium

Uranium is most common fuel in the Nuclear reactors. Uranium is produced by a number of countries and major suppliers that are politically stable such as Canada and Australia. Uranium resources are plentiful and increasing. With the current demand level of some 67,000 tonnes per year (2006), identified uranium reserves (5.5 million tonnes) are sufficient for around 100 years. The fuel cost of uranium in a nuclear power plant is approximately 9-10 $/MWh. (IEA ETSAP, n.d.-b)

(d) Coal

Pulverized coal is the fuel used by approximately 97% of the world's coal-fired power plant (International Energy Agency, 2008). In a pulverized coal-fired power plant, coal is milled and burned with air in tall boilers that provide for complete burnout and efficient heat transfer. The fuel cost considered for coal power plants is 15-25 $/MWh (Energy Technology System Analysis Programme, 2010).

5.6.2 Capital & Fixed Costs

The amount of investment needed for construction and commissioning of a new technology is taken into account in capital costs. The fixed costs of a technology include the operation and maintenance costs of that technology.

The capital costs of a technology vary with the year of investment. The capital costs of certain technologies (solar, wind, etc.) decrease with time as the technology matures and new techniques of fabrication and improved efficiencies take over the existing ones. However for some technologies the capital costs are expected to increase. For instance a clean power production from coal power plant will require more investment in the future as the environmental regulations are further tightened.

5.6.3 Investment Restrictions

To model the Kenyan energy sector as accurately as possible, investment restrictions are introduced for the years 2014-2017, being the period for which the data on installed capacities are available. The residual capacities are introduced in the model as the upper limits for the investments during this period. The generation mix and the capacity installed from 2014 to 2017 are fixed with historical values.

5.6.4 Discount Rate

The Central Bank of Kenya kept its benchmark interest rate steady at 9.5 percent at May 28, 2018. The discount rate in Kenya is expected to vary between 9-11% according to Central Bank of Kenya. In OSeMOSYS the discount rate of 10% is considered and a sensitivity analysis is performed for the likely variation to occur.

5.7 Emission Accounting & Renewable Energy

Electricity and heat production from thermal power plants is a significant source of both air pollutants and greenhouse gas emissions. Reducing the emissions per unit of electricity and heat produced (emissions intensity) of these plants can play an important role in helping to reduce their environmental impacts. The emissions considered in this model include the NOx and CO_2 emissions.

5.7.1 NO_X Emissions

NOx is a generic term for the nitrogen oxides that are most relevant for air pollution, namely nitric oxide (NO) and nitrogen dioxide (NO2). These gases contribute to the formation of smog and acid rain, as well as affecting tropospheric ozone. NOx emissions for fossil fuel based power plants are listed in *Table **6*** (Mittal, 2010).

Power Plant	NOx Emissions (g/kWh)	NOx Emissions (kton/PJ)
Coal	4.4	1.222
NG	1.04	0.289
Diesel	13	3.611

Table 6 NOX Emissions for fossil fuel based power plants.

The CO_2 emissions (kton/PJ) are calculated on the basis of type and quality of fuel (Ching-Yi Emily Hung, 2009).

5.7.2 CO_2 Emissions

The CO_2 emissions contribute to climate change which can have serious consequences on human health and the environment. The carbon di oxide intensity for Total Primary Energy Supply in Kenya is very low (0.31 tonnes CO_2/ capita (IEA, n.d.)) compared to other developing countries.

The CO_2 emissions are accounted based on the amount of fuel usage and is calculated for each fuel below.

(a) Coal

There is commercially viable coal reserve in the Mui Basin situated in Kitui County. The coal has been analyzed and found to range in ranking from lignite to sub-bituminous with calorific values between 16 and 27 MJ/kg (Ministry of Energy and Petroleum, 2014) This paper assumes the Carbon content of indigenous coal to be 0.60kgc/kgcoal of coal and a heating value of 22,000 kJ/kg.

$$\left(CO_2\right)_{\text{indigenous coal}} = 0.60kg_C \times \frac{44kg_{CO_2}}{12kg_C} = 2.2\frac{kg_{CO_2}}{kg_{coal}}$$

$$\left(CO_2\right)_{\text{indigenous coal}} = \frac{2.2\dfrac{kg_{CO_2}}{kg_{coal}}}{22000\dfrac{kJ}{kg_{coal}}} = 10\times10^{-5}\frac{kg_{CO_2}}{kJ} = 100\frac{kton_{CO_2}}{PJ} \tag{1.1}$$

Hence 100 kton CO_2 production (1.1) is considered for every Peta-Joule of energy from indigenous coal.

Coal imported into Kenya is mostly bituminous, with a carbon content of 0.65kgc/kgcoal and heating value of 28,000kJ/kg. (Ministry of Energy and Petroleum, 2014)

$$\left(CO_2\right)_{\text{imported coal}} = 0.65kg_C \times \frac{44kg_{CO_2}}{12kg_C} = 2.38\frac{kg_{CO_2}}{kg_{coal}}$$

$$\left(CO_2\right)_{\text{imported coal}} = \frac{2.38\dfrac{kg_{CO_2}}{kg_{coal}}}{28000\dfrac{kJ}{kg_{coal}}} = 8.5\times10^{-5}\frac{kg_{CO_2}}{kJ} = 85\frac{kton_{CO_2}}{PJ} \tag{1.2}$$

Hence 85 kton CO_2 production (1.2) is considered for every Peta-Joule of energy from imported coal.

(b) Natural Gas

Natural gas has 74% carbon by weight and a heating value of 54,000kJ/kg (Heat Values of Various Fuels, 2016).

$$\left(CO_2\right)_{natural\,gas} = 0.74kg_C \times \frac{44kg_{CO_2}}{12kg_C} = 2.71\frac{kg_{CO_2}}{kg_{\text{natural gas}}}$$

$$\left(CO_2\right)_{natural\,gas} = \frac{2.71\dfrac{kg_{CO_2}}{kg_{natural\,gas}}}{54000\dfrac{kJ}{kg_{natural\,gas}}} = 5.0\times10^{-5}\frac{kg_{CO_2}}{kJ} = 50\frac{kton_{CO_2}}{PJ} \tag{1.3}$$

Hence 50 kton of CO_2 production (1.3) is considered for every Peta-Joule of energy from natural gas.

(c) Oil

Kenya recently discovered small amounts of commercially viable oil reserves but the production and use of indigenous oil is still being explored. Kenya's electricity sector relies considerably on imported crude oil and distillates. Most of the oil imported in Kenya is from Abu Dhabi and Saudi Arabia. This paper assumes that oil being used for the electricity generation in power plants is imported distillate oil consisting 87% by weight carbon content with a heating value of 45,000kJ/kg (Heat Values of Various

Fuels, 2016).

$$\left(CO_2\right)_{Oil} = 0.87 kg_C \times \frac{44 kg_{CO_2}}{12 kg_C} = 3.19 \frac{kg_{CO_2}}{kg_{Oil}}$$

$$\left(CO_2\right)_{Oil} = \frac{3.19 \frac{kg_{CO_2}}{kg_{Oil}}}{45000 \frac{kJ}{kg_{Oil}}} = 7.0 \times 10^{-5} \frac{kg_{CO_2}}{kJ} = 70 \frac{kton_{CO_2}}{PJ} \quad (1.4)$$

Hence 70 kton of CO_2 production (1.4) is considered for every Peta-Joule of energy from oil.

(d) Renewables

Non-fossil fuel based technologies such as; wind, photovoltaic (PV), hydro, biomass [1] and nuclear are often referred to as “low carbon” or “carbon neutral” because they do not emit CO_2 during their operation i.e. no direct emissions. However, they are not “carbon free” as CO_2 emissions -indirect emissions- do arise during other phases of their life cycle such as extraction, construction, maintenance and decommissioning (Ching-Yi Emily Hung, 2009). In this model neither the direct nor the indirect CO_2 or NOx emissions for the renewable technologies were considered. Also the contribution of indirect emissions to the annual CO_2 or NOx emissions from non-renewable technologies was ignored.

5.7.3 Renewable Energy

The model considered the following power generation technologies as renewable energy technologies.

i. Solar photo-voltaic technologies.
ii. Solar CSP technology.
iii. Wind power plants.
iv. Geothermal power technology.
v. Biomass power plants.
vi. Hydro power plants.

The government’s or the international agencies set targets for the uptake of renewable technologies in the energy mix imply planned investments in the afore-mentioned technologies.

Although there are no direct emissions from the renewable technologies except for biomass usage, the indirect emissions may arise during other phases such as during fabrication and transportation. Biomass is considered as a carbon neutral source so even the direct emissions from the use of biomass are ignored. In this study we will consider only the direct emissions from the power plants hence all the renewable technologies are considered emission free.

5.7 Electricity Demand

5.7.1 Population Growth Projections

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[1] Biomass is considered a renewable energy source when the utilization rate is equal to, or lower than the capacity of production (biological capacity of renewal). The energy exploitation of renewable biomass is a CO_2-neutral (or almost neutral) process.

The projected rise in world population to 9.2 billion in 2050 represents an increase of 2.7 billion over the 2005 population of 6.5 billion (Bongaarts, 2009). Nearly all of this future growth will occur in the South i.e. Africa, Asia and Latin America

The population growth continues at a rapid pace in sub-Saharan Africa. In Kenya peak growth rates approached four per cent per year in recent decades (implying a doubling of population size in two decades), levels that were very rarely observed in developed countries except with massive immigration. Two factors account for this very rapid expansion of population in these still largely traditional societies: the spread of medical technology (e.g. immunization, antibiotics) after World War II, which led to extremely rapid declines in death rates, and a lag in declines in birth rates.

The *Figure 27* shows the population growth in Kenya (United Nations, Department of Economic and Social Affairs, 2017) over the modeling period.

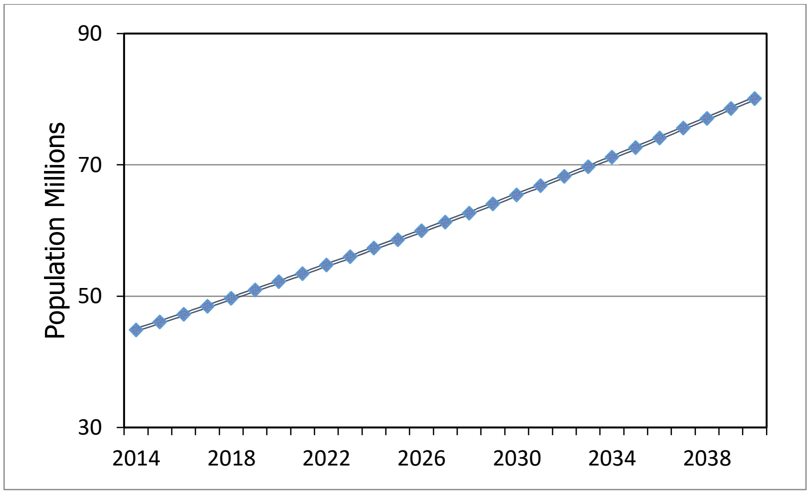

Figure 27 Population growth projections for Kenya

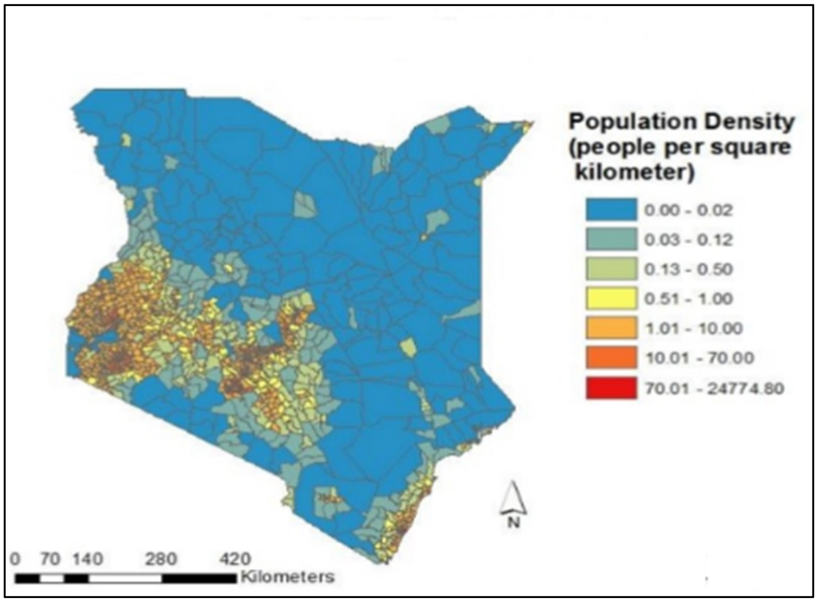

Figure 28. Population density in various regions of Kenya. (Valerie Benka, 2012)

5.7.2 Geospatial Resolution

The Kenya National Control Centre divides electricity demand into four major regions, namely Nairobi Region, Coast region West Region and Mount Kenya region. The demand in each of these regions vary significantly with maximum demand in Nairobi region as it is most densely populated followed by West region, Coast Region and the least demand in Mt. Kenya Region.

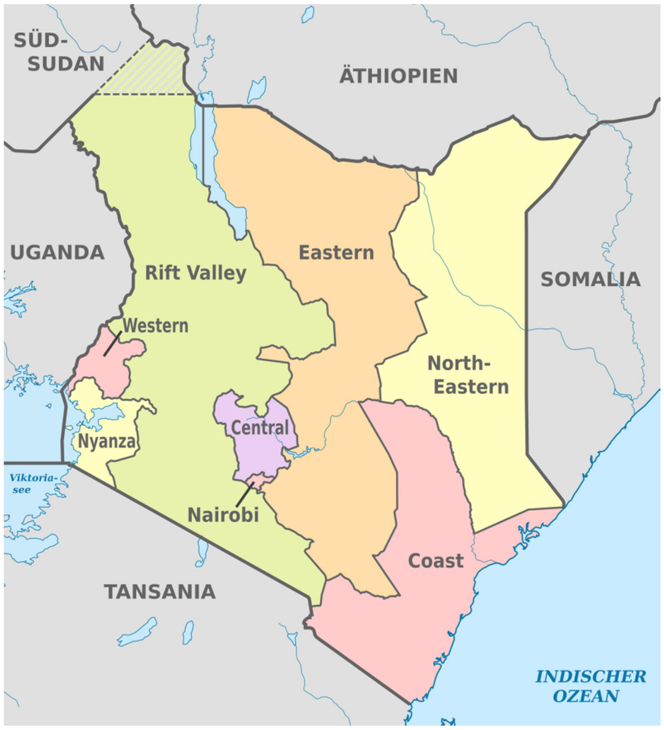

Figure 29. Division of Kenya's regions

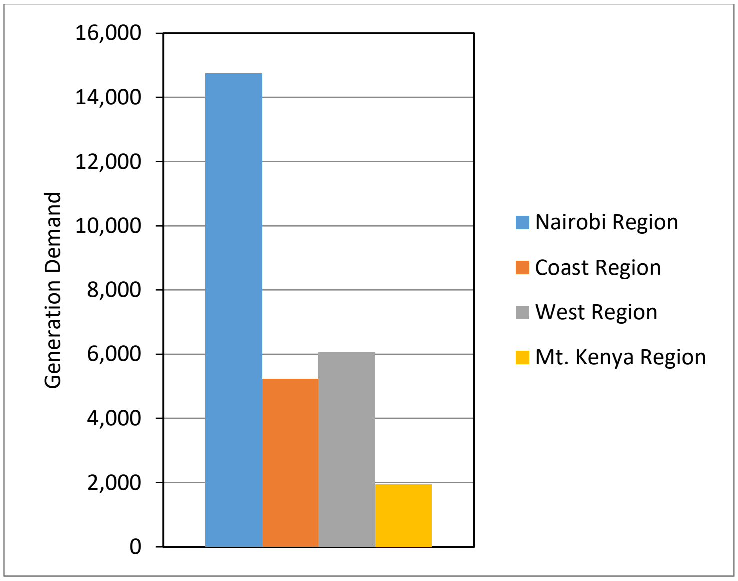

Figure 30 Electricity demand in different regions. **(Kenya Power & Lighting Company Ltd., 2017)**

5.7.3 Electrification Rates

The electrification rate in Kenya has been growing at a fast rate. KPLC has been tasked with the responsibility of connecting people to the grid in order to up lift their living standards.

Two different electrification rate scenarios are considered. The New Policies Scenario considers a fast electrification rate to achieve 99% electricity access by 2030. The Gok and 100% Renewable scenario considers that the electrification rate in the country increase but at a slower pace than that assumed in New Policies scenario. Towards the end of the modeling period the growth in the electrification rate slows down in both the scenarios as the remaining unconnected communities are much more distributed and hard to access.

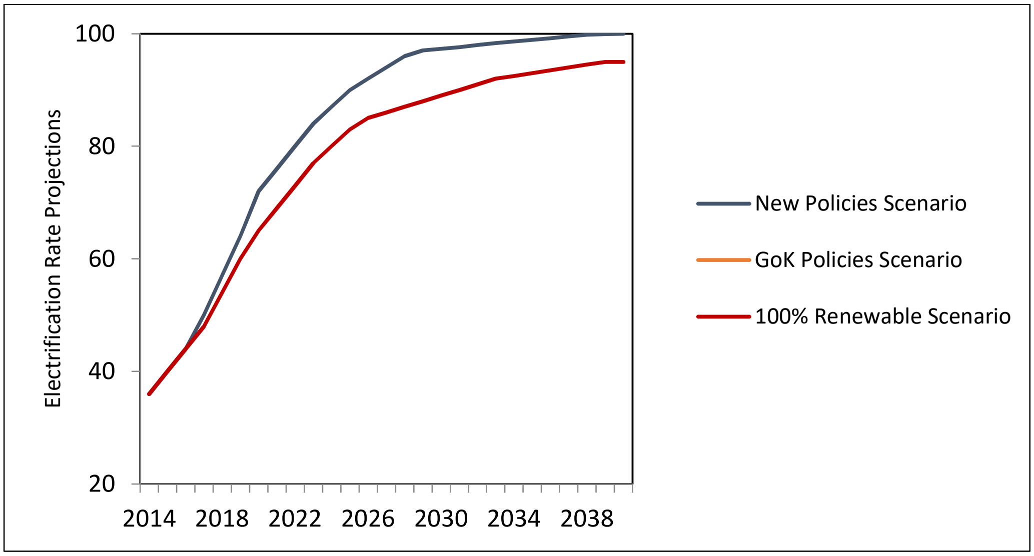

Figure 31 Electrification rate projections for Kenya.

5.7.4 Specified Demand Profile

Specified demand profile defines the fraction of demand during each time-slice of the year. This is defined based on the demand data for 2016 (Kenya Power & Lighting Company Ltd., 2017). The actual demand during each time period is divided by the total demand of the year to get the fractional demand during that time-slice. The specified annual demand profile values are defined in Appedix C.

5.7.5 Total Annual Demand

The bottom up approach is used to define the demand of electricity. In this approach the load of exceptionally large projects called flagship projects is added on top of the consumer growth.

The annual consumer demand of electricity in Kenya is calculated as follows.

$$\mathrm{SAD} = \mathrm{Popul} * \mathrm{C} * \mathrm{HH} * \mathrm{ER} * \mathrm{CF}$$

- SAD = Specified Annual Demand [PJ/y]
- Pop = Total population
- C = consumption per household [kWh/households]

- HH=people per household [persons/household]
- ER = electrification rate, % of people with access to electricity [%]
- CF = conversion factor 3,6*10-9 [PJ/kWh]

Total population divided by the number of households gives the average number of people per households. According to the report of Kenya Vision 2030 in 2011 the number of people per household was 5 in urban areas and 6.5 in rural areas. As the economic growth reaches a rapid pace as expected in Kenya this number is expected to decrease. However the urbanization rate is expected to increase in Kneya.(World Bank, 2016)

Year	2010	2030	2040
Urbanization	25%	30%	45%
Total Person/ HH	6.125	5.75	4.875
Urban Person/ HH	5	4	3.5
Rural Person/ HH	6.5	6.5	6

Table 7 Urbanization and house hold size projections.

The specific demand increases in both the urban and the rural areas but the consumption in the urban areas remains higher than in rural areas. The specific energy consumption varies in different scenarios. A steady increase is expected in specific energy consumption however towards the end of the modeling period the growth decreases in the New polices scenario as the energy efficient consumption trend increases.

The load of flagship projects which include Lamu port resort cities, Economic zones, Railway lines etc. are included in the Vision scenario demand load calculation.

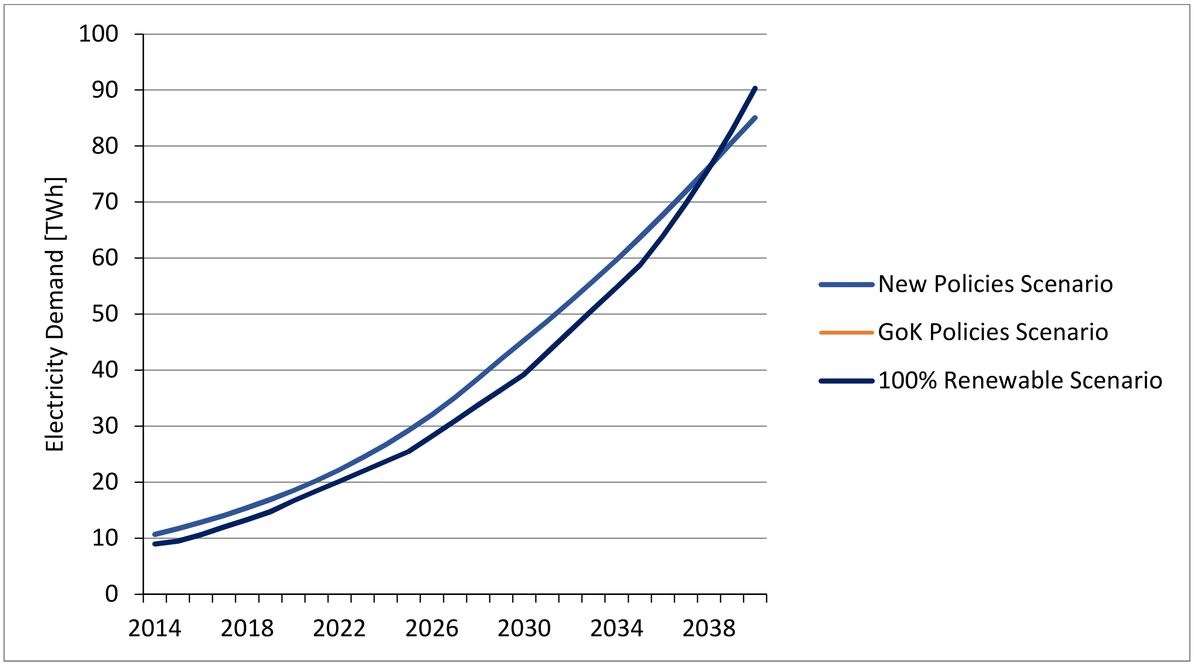

Figure 32 Electricity Demand growth projections.

6 RESULTS

The 44.8 million population of Kenya in 2014 roughly doubles to 80.09 million in 2040 (United Nations, Department of Economic and Social Affairs, 2017). The high population growth rate of Kenya complemented by increased energy consumption per capita creates an ever increasing demand for energy and energy services. *Table **8*** shows the specific consumption of electricity in both scenarios. The specific consumption in GoK policies scenario increases consistently while in the New Policies scenario a sharp increase is seen in the start of the modeling period while it slows down towards the end because an energy efficient consumption is assumed. Also electrification rate in the country increases rapidly with large number of new connections being added each year. The analysis of scenarios is provided below.

6.1 GoK policies scenario

The annual energy production starting from 32 PJ in 2014 as shown in *Figure **33*** increases to roughly 325 PJ in 2040 in order to meet the demand of electricity. Historical actual production of electricity form different technologies are shown prior to 2017 which shows a dominant electricity production from hydro and geothermal technologies (KPLC, 2017).

Years	Population	GoK Policies	New Policies	100% Renewable
	x1000	kWh/capita	kWh/capita	kWh/capita
2020	52,187	319	354	319
2030	65,412	600	694	600
2040	80,091	1127	1062	1127

Table 8 Specific Consumption in different scenarios

A major portion of the energy production through the modeling period is provided by the geothermal power plants which accounts for 18% of the total installed capacity in 2040 (*Figure **39***). Geothermal is seen as most suitable candidate for base load expansion. The annual capacities of hydro power plants which include; small hydro, dam hydro and run-of-the-river hydro power plants decrease steadily over the model period due to degradation of power generation capacities. No new investment in the hydro power plants is observed (*Figure **34***) because of the high capital costs associated to the development of these technologies. However residual capacity of hydro-power plants contributes to the energy production during the modeling period. The share of hydro in the energy mix reduces from 35% in 2017 (*Figure **42***) to 2% in 2040 (*Figure **39***). Natural gas single cycle gas turbines provide the backup capacity (about 18% of the total installed capacity in 2040). The government's intention of investment in Nuclear energy accounts for almost 8% (4000 MW) of the final energy mix. Production of electricity from Nuclear power plants start in 2022 offsetting the energy production from other technologies.

Years	Population	GoK Policies	New Policies	100% Renewable
	x1000	tones CO_2/ GWh	tones CO_2/ GWh	tones CO_2/ GWh
2020	52,187	46.47	204.38	46
2030	65,412	77.47	120.12	0
2040	80,091	43.75	49.09	0

Table 9 Carbon intensity of electricity production

The solar photovoltaic technology boasts the major portion (43%) of the total installed capacity (*Figure **39***) in 2040. The share of annual energy production (*Figure **33***) from PV technologies increase steadily over the modeling period as the costs associated with the development of new capacity reduces. Solar PV is observed to contribute a major share towards power generation from off grid technologies.

Diesel distributed generation technology complements the off-grid power generation from solar at times when the solar energy is not available. A share of 10% (*Figure **39***) of total installed capacity is observed in 2040.

CO_2 emissions show an increasing trend in *Figure **33*** with sudden depressions observed when the new capacities of nuclear power plants are commissioned. The carbon intensity for electricity production is shown in *Table **9*** and is well below the EU 28 average of 340 tonnes CO_2/GWh (Moro & Lonza, 2017).

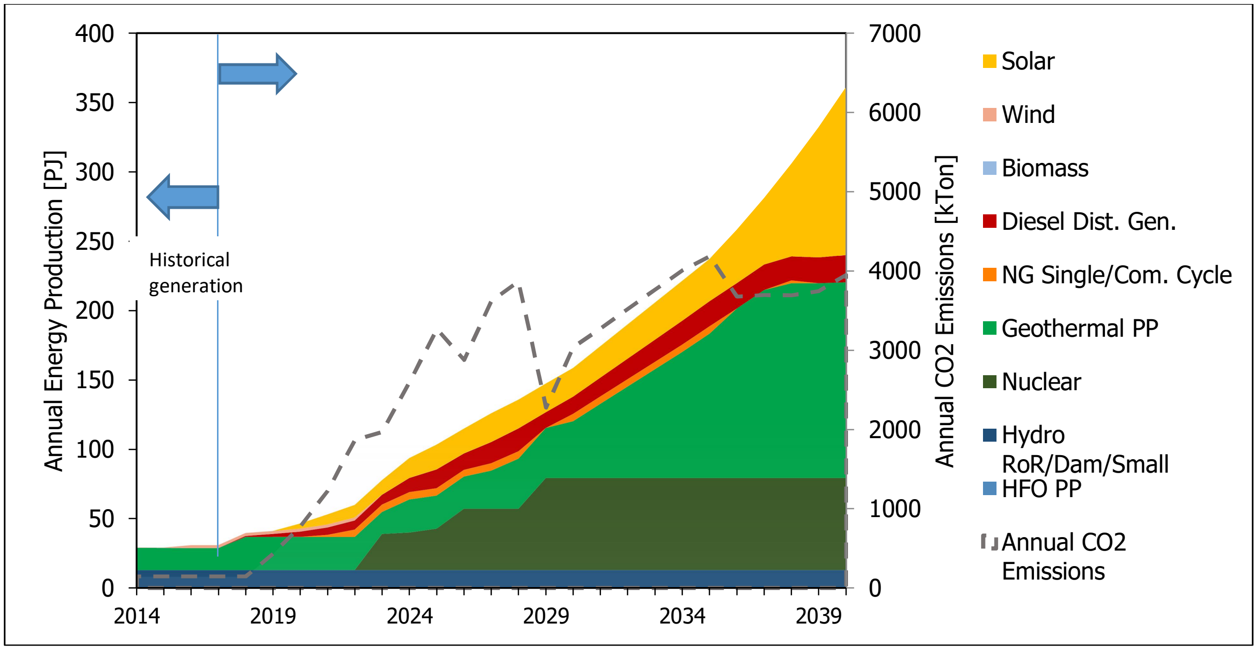

Figure 33 Annual energy production (PJ) & annual total CO2 emissions (kton). GoK policies scenario.

Annual new capacity investment (*Figure **34***) illustrates the trend of growing investment required in the electricity sector, starting from approximately 0.3 GW in 2015 reaching to more than 3 GW in 2040.

More investment in nuclear technology is seen in the beginning with solar clearly overtaking other technologies towards the end of the modeling period.

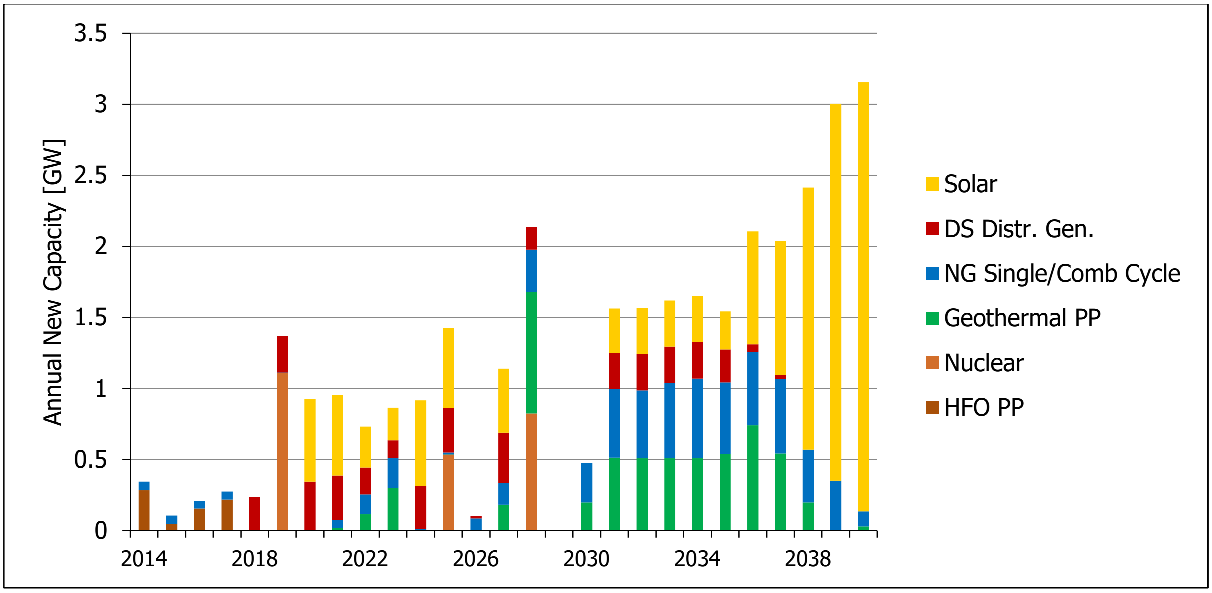

Figure 34 Annual new capacity investment (GW). GoK policies scenario

6.2 New policies Scenario

The annual energy production for the new policies scenario is illustrated in *Figure* ***35***. In this case the estimated demand is lower than that for the GoK policies scenario. Since no restrictions are placed on the model and the government policies for investment in a particular technology are ignored, the model chooses the technologies which produce electricity at the minimum cost to meet the demand without any constraints. The energy production in this scenario is largely dominated by geothermal power plants producing 62% of the total energy production (*Figure* ***35***). Geothermal power plants account for 26% of the total installed capacity in 2040 (*Figure* ***40***). The residual capacity of hydro-power plants as seen in the previous case contribute to the annual energy production but its share decreases in successive years as no new capacity investment in this technology is seen (*Figure* ***36***). A large share (27%) of Natural gas single cycle and combined cycle power plants is also observed (*Figure* ***40***) as it provides the major backup capacity and peak capacity. It is interesting to note that the energy mix excludes the nuclear power generation technology in this scenario as it is not the cheapest option in Kenyan context.

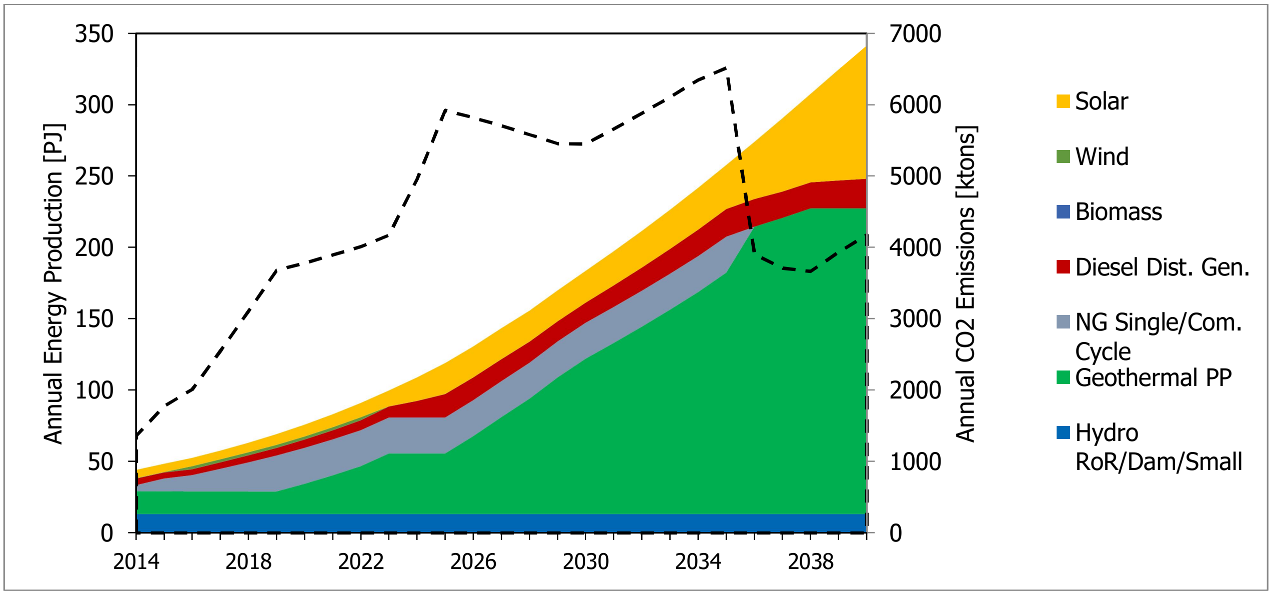

Figure 35 Annual energy production (PJ) & annual total CO2 emissions (kton). New policies scenario.

The PV technologies in both urban and rural areas are preferred especially in the latter part of the modeling period. This is mainly because costs related to the PV technologies are assumed to continuously decrease over time owing to an increase in efficiency of PV technologies, reducing the size of the PV panels/kW hence material costs. Improvement in fabrication techniques is also predicted to reduce manufacturing costs significantly. Solar photovoltaic technology becomes increasingly important technology in the energy mix contributing 34% of the total installed capacity in 2040.

A distributed generation capacity of Diesel power plants (11%) is observed which complements the off-grid power generation from solar PV technologies.

The new capacity investment graph (*Figure **36***) shows the annual capacity additions to the existing capacity in order to satisfy the increasing demand. A high investment in the first year of the modeling period is observed in order to compensate the wide gap that exists in the demand of electricity and the supply capacity. The capacity additions increase each year but reduce towards the end of the modeling period as an efficient consumption of electricity and reduction in the growth rate of population is assumed.

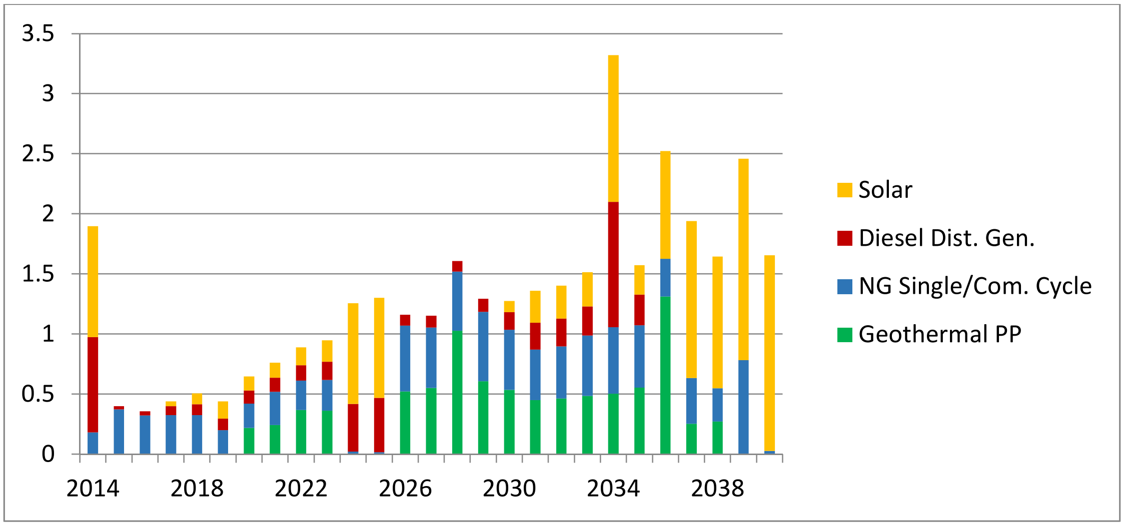

Figure 36 Annual new capacity investment (GW). New Policies Scenario.

The CO2 emissions (*Figure* ***35***) increase as the power production from Natural gas power plants is increased. Towards the end of the modeling period the power production from Natural gas power plants Is taken over by geothermal hence a decline in CO2 emissions is observed. The carbon intensity in this scenario is mentioned in *Table* ***9***.

6.3 100% Renewable Scenario

Power production from only renewable technologies is seen after the target year 2030 (*Figure* ***37***). Since the model settings in this scenario are the same as defined in GoK policies scenario the model takes into account the government intentions of Nuclear power development. *Figure* ***37*** shows that for this scenario Diesel and Natural gas power generation technologies play a small role in power production. After 2030 Solar PV technology contribution in the overall power production increases the most followed by the geothermal technology. Investment in Concentrated solar power technology is also observed as illustrated in *Figure* ***38***. Nuclear power plants built in line with the government intentions continue to provide power to the grid (*Figure* ***38***).

A large share -52%- (*Figure* ***41***) of total capacity is largely provided by solar technologies in 2040. Natural Gas and geothermal power plants contribute 21% and 17% respectively. The nuclear capacity available in 2040 is about 8% and the remaining 2% is contributed by hydro power generation.

Although no energy generation is observed from Natural gas power plants after 2030 they provide the back-up capacity to increase the system reliability.

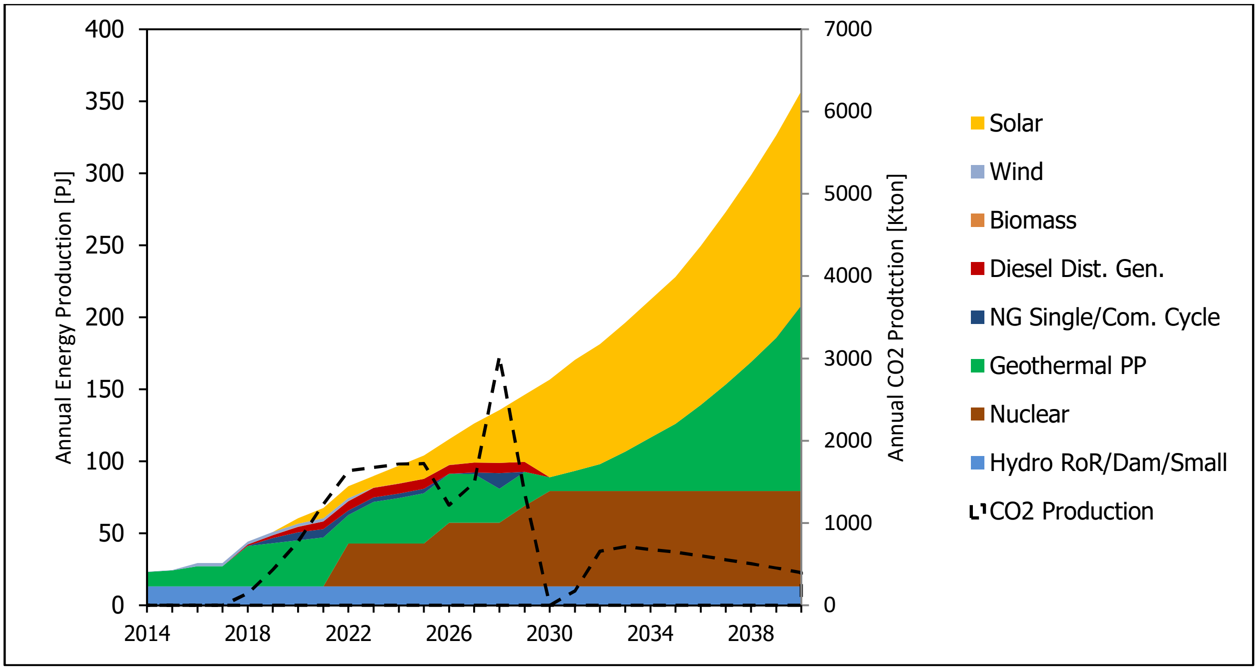

Figure 37 Annual energy production (PJ) & annual total CO2 emissions (kton). 100% Renewable Scenario.

A small amount of new capacity investment (*Figure **38***) is observed in thermal (diesel and HFO) power plants during the start of the modeling period because a short time period is required for their commissioning. However in the rest of the modeling period we observe huge investment in solar technologies followed by geothermal and NG open and combined cycles.

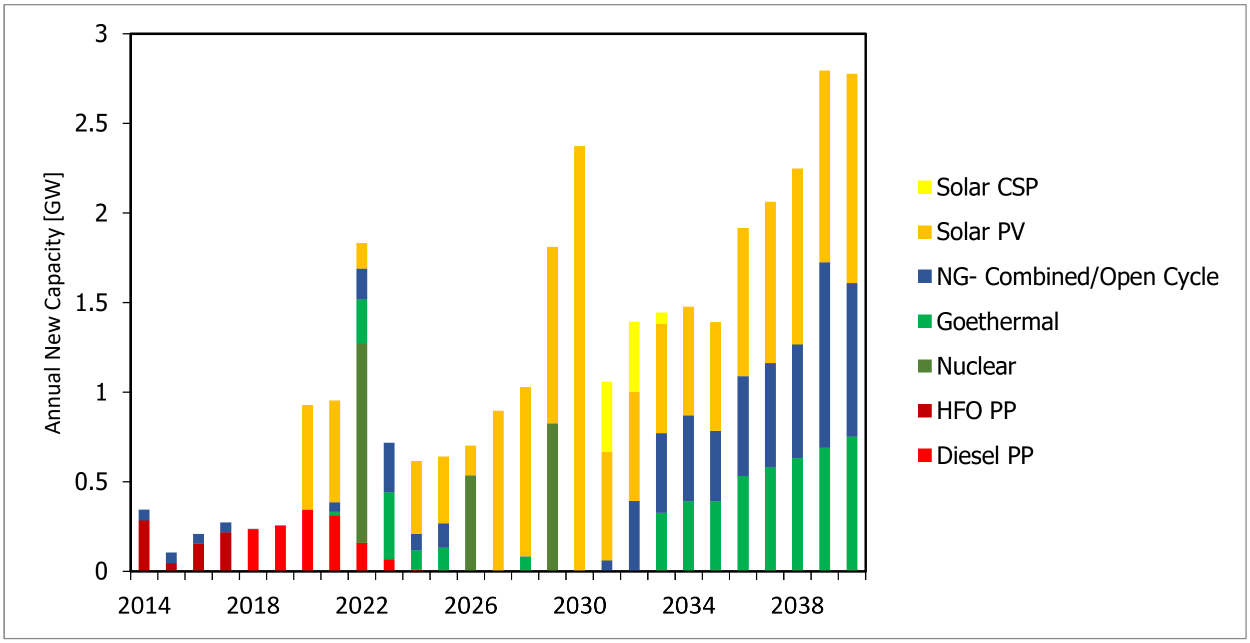

Figure 38 Annual new capacity investment (GW). 100% Renewable Scenario.

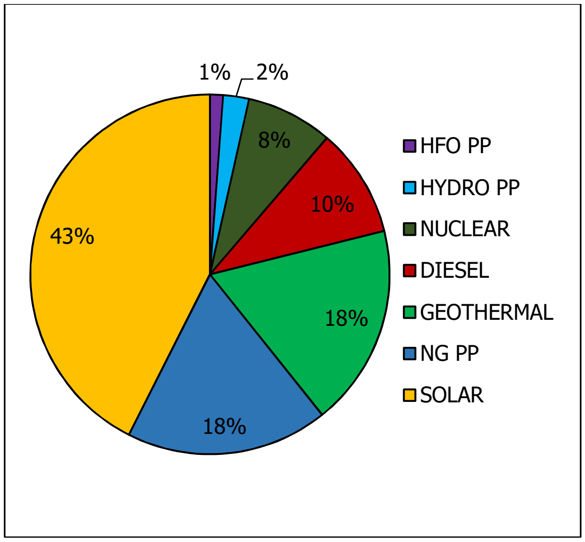

Figure 39 Power Generation Technologies mix GoK Policies Scenario.

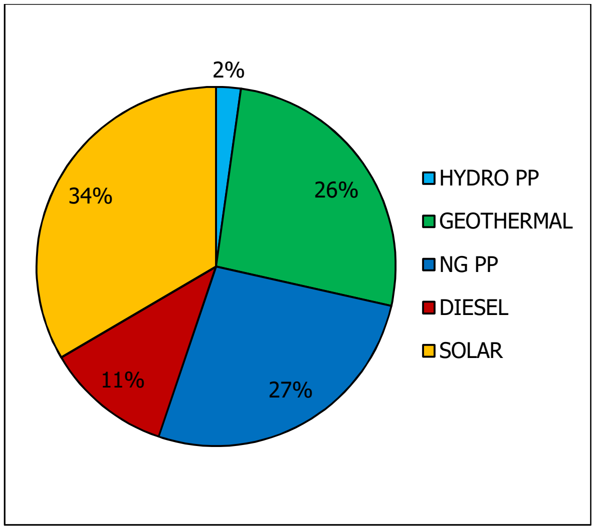

Figure 40 Power generation technologies mix New Policies Scenario.

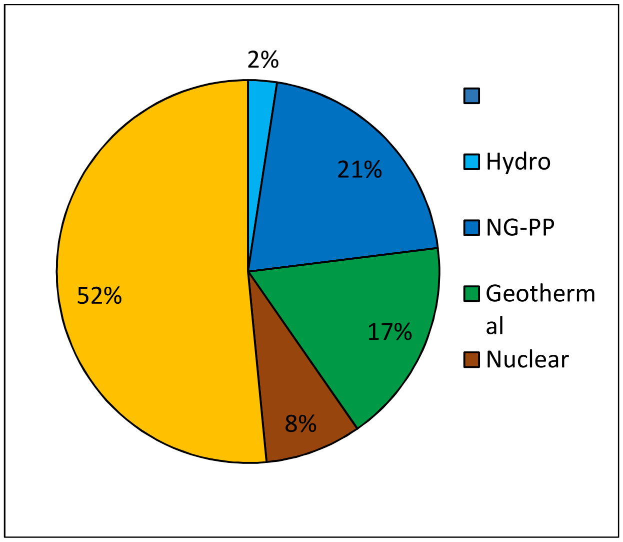

Figure 41 Power Generation Technologies mix 100% Renewable Scenario.

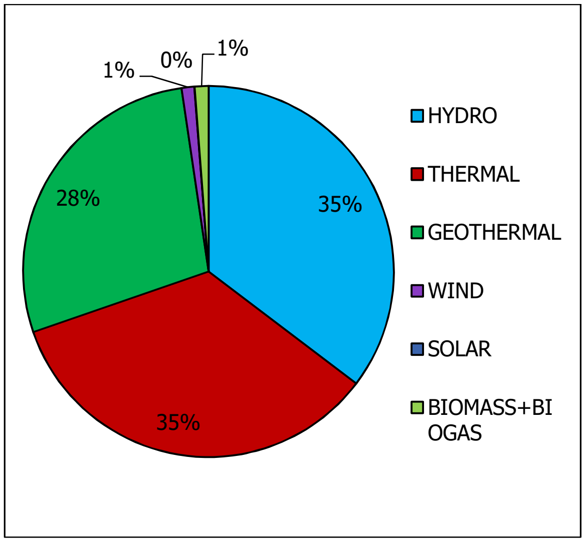

Figure 42 Power Generation Technologies mix Actual 2016

7 DISCUSSION

The study analyzed the implications in three different scenarios of electricity demand and government policies on the future generation capacities, CO2 emissions and annual new capacity investments. The analysis of scenarios highlight the importance of geothermal energy for base load power generation and solar-PV power plants complemented by distributed diesel power generation for off-grid electrification in Kenya.

Geothermal energy is the clean and cheap source of energy. Kenya is endowed with massive geothermal resource potential estimated close to 12000 MW (Energypedia, n.d.). Geothermal plants generally operate as base-load generators with capacity factors comparable to or higher than conventional generation. Capital costs are very site-specific, varying significantly with the characteristics of the local resource system and reservoir. Thus, high potential of geothermal resource in Kenya and its comparatively low cost of utilization make it very competitive for power production.

The high Global Horizontal Irradiation is observed towards the North Western and towards the southern and eastern side of the country comprising of coastal region. These regions are relatively densely populated compared to the Northern and the North Western regions. Hence the use of solar technology in these regions for power generation purposes is economically viable.

Power generation capacities in both the scenarios comprise largely of renewable technologies accounting for 71% in GoK policies scenario and 62% in New Policies scenario.

A sensitivity analysis was performed on the most uncertain parameters. The possible variation of the fuel costs of Natural gas and Oil from the projected one as shown in *Figure 43* was used for the sensitivity analysis. Also the variation of cost of solar-PV because of low and high technological advancement is considered for sensitivity analysis.

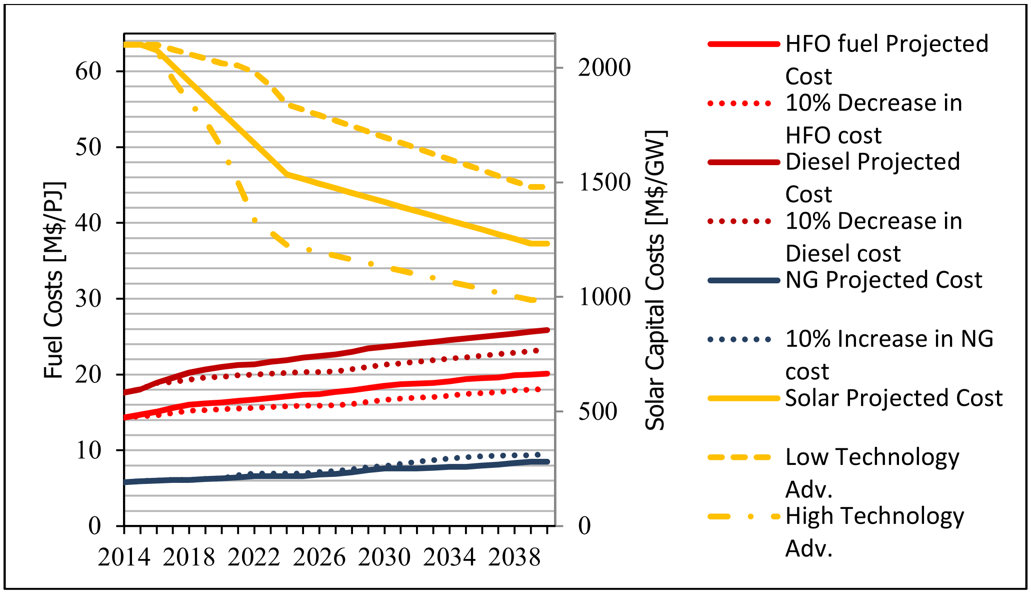

Figure 43 Fuel prices and capital cost projections and likely variations.

It is observed that increase in the natural gas fuel prices have a little effect on Annual capacity while a decreased oil prices (Energy Information Administration, n.d.) favor considerably the distributed diesel power plants which complement the development of off-grid solar-PV (*Figure 44*). A high technological advancement in solar-PV will lead to reduced costs hence more capacity investment in this technology while offsetting the capacity of geothermal and natural gas power plants on the contrary higher cost than projected of solar-PV will increase the share of geothermal, natural gas power plants in the overall energy mix.

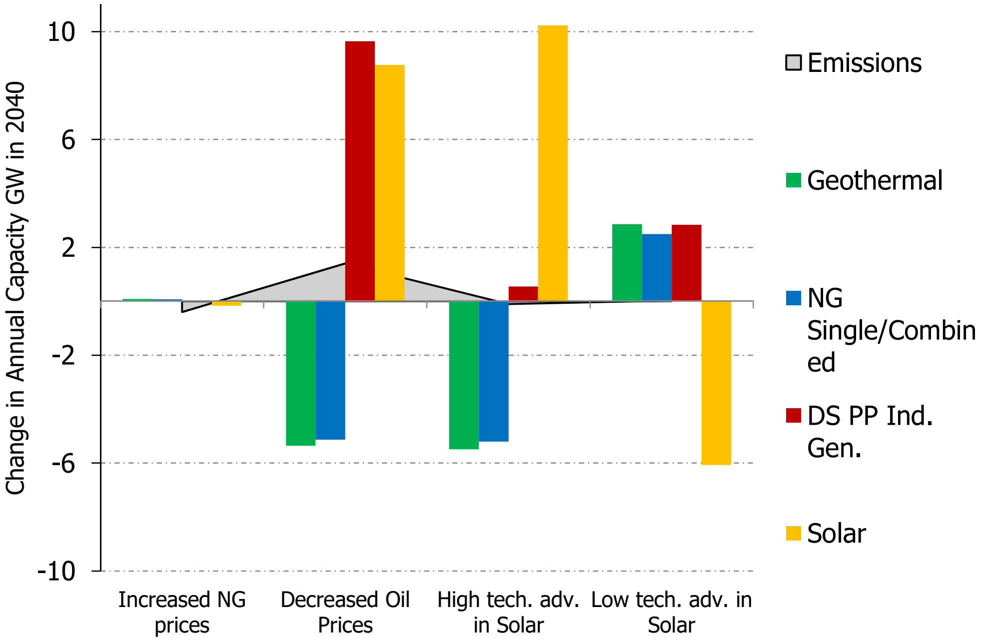

Figure 44 Sensitivity Analysis

8 CONCLUSION

Access to affordable clean sources of energy especially electricity access is an issue of core importance in policy making for governments in Africa and the international organizations. The energy modeling techniques help in analyzing scenarios that may emerge as result of different policies of both governments and international institutions. Because of the ambitious development objectives of Kenya or the universal energy access goal by 2030 of the United Nations, it’s nowadays, more than ever, of utmost importance to improve the reliability of the energy modeling tools in order to provide the best technical support to the decision makers. This work hopes to contribute to this goal both by providing an assessment of the scenario that might emerge because of government and IEA policies and a critical analysis of impact, the variation in key input parameters could have on the main outcomes of the energy modeling.

In order to satisfy the acutely growing demand for electricity in Kenya a huge investment is required in the power generation, transmission and distribution sectors. The results clearly emphasize the need to further develop the geothermal power generation because of its abundant potential in Kenya. Solar photo-voltaic modules widely being used in rural Kenya provide the most cost-effective solution to satisfy the demand for electricity in areas far from the grid. Solar PV systems are expected to become popular and compete with the on grid technologies as the technology matures and the costs related to generation and storage sharply decrease. However provision of stable, reliable and flexible supply of electricity requires increased connectivity to the grid.

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APPENDICES

Appendix A

The technologies and the fuels considered in the OSeMOSYS model are listed in this section.

TABLE.A1. ELECTRICITY GENERATION TECHNOLOGIES CONSIDERED IN THE OSEMOSYS MODEL

NO.	TECHNOLOGY DESCRIPTION
1	Biomass Combined Heat & Power (CHP) plant
2	Coal power plant
3	Diesel power plants (100kW, Industry) Off- Grid Power Generation
4	Diesel power plants (1kW, Rural, Residential/Commercial) Off- Grid Power Generation
5	Diesel power plants (1kW, Urban, Residential/Commercial) Off- Grid Power Generation
6	Diesel power plants (Utility)
7	Geothermal power plant (Single Flash)
8	Oil fired gas turbine OIL Single Cycle Gas Turbine
9	Small hydro power plant (SHP)
10	Dam hydro power plant
11	Run-of-river hydro power plant
12	Natural gas (Combined Cycle) NGCC.
13	Natural gas (Single Cycle) NGSC
14	Concentrated Solar Power CSP (Without storage)
15	Concentrated Solar Power CSP (With storage)
16	Concentrated Solar Power CSP (With gas firing)
17	Solar Photovoltaic Power Plant (Utility Scale)
18	Solar Photovoltaic Power Plant (Roof top, Rural), Off- Grid Power Generation
19	Solar PV with storage (1 hr, Rural) Off- Grid Power Generation
20	Solar PV with storage (2 hr, Rural) Off- Grid Power Generation
21	Solar PV (Roof top, Urban) Off- Grid Power Generation
22	Solar PV with storage (1 hr, Urban) Off- Grid Power Generation
23	Solar PV with storage (2 hr, Urban) Off- Grid Power Generation
24	Wind (Onshore, 20% CF)
25	Wind (Onshore, 30% CF)
26	Nuclear Technology

TABLE A2 FUELS CONSIDERED AS INPUT TO POWER GENERATION TECHNOLOGIES

NO.	FUELS
1	Natural Gas (Imported & Indigenous Extraction)[2]
2	Coal (Imported & Indigenous Extraction)

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[2] The costs of imported fuels and the indigenous extraction of fuels are different and are defined separately in the import or extraction technologies for each fuel.

3	Diesel (Imported & Indigenous Extraction)
4	Heavy Fuel Oil (Imported & Indigenous Extraction)
5	Nuclear fuel ‘Uranium’ (Imported)
6	Biomass (Indigenous Extraction)

Appendix B

The nomenclature and the units used in this paper are explained in this appendix.

TABLE B1 NOMENCLATURE

NO	NAME	DESCRIPTION	SYMBOL
1	Emissions	The EMISSION (CO_2, NO_x) to be accounted for.	e
2	Technology	The TECHNOLOGYs modeled.	t
3	Fuels	The FUELS used.	f
4	Year	The YEARs modeled.	y
5	Time slice	The TIMESLICEs, each of which combines a fraction of the year with specific load and supply characteristics.	l
6	Region	The REGIONS that are to be modeled. Kenya is modeled as one region	r

TABLE.B2. UNITS

NO.	UNIT	DESCRIPTION
1	MW	Mega Watts (10^6 Watts)
2	GW	Giga Watts (10^9 Watts)
3	kWh	Kilo Watt Hours (10^3 Watt hours)
4	MWh	Mega Watt Hours (10^6 Watt Hours)
5	GWh	Giga Watt Hours (10^9 Watt hours)
6	TWh	Tera Watt Hours (10^{12} Watt hours)
7	PJ	Peta Joules (10^{15} Joules)
8	MJ/kg	Mega joules per kilogram
9	kJ/kg	Kilo Joules per kilogram
10	kton	Kilo tones (10^3 tones)

Appendix C

TABLE.C1. TIME-SLICES DIVISION

Month	Days	Monthly Fraction	Hours in each time-slice	Time-Slice Fraction
January	31	0.084932	12	0.042466
	31		4	0.014155
	31		8	0.028311
February	28	0.076712	12	0.038356
	28		4	0.012785
	28		8	0.025571
March	31	0.084932	12	0.042466
	31		4	0.014155
	31		8	0.028311
April	30	0.082192	12	0.041096
	30		4	0.013699
	30		8	0.027397
May	31	0.084932	12	0.042466
	31		4	0.014155
	31		8	0.028311
June	30	0.082192	12	0.041096
	30		4	0.013699
	30		8	0.027397
July	31	0.084932	12	0.042466
	31		4	0.014155
	31		8	0.028311
August	31	0.084932	12	0.042466
	31		4	0.014155
	31		8	0.028311
September	30	0.082192	12	0.041096
	30		4	0.013699
	30		8	0.027397
October	31	0.084932	12	0.042466
	31		4	0.014155
	31		8	0.028311
November	30	0.082192	12	0.041096
	30		4	0.013699
	30		8	0.027397
December	31	0.084932	12	0.042466
	31		4	0.014155

	31		8	0.028311
Total	365	1	24	1

TABLE.C2. SPECIFIED ANNUAL DEMAND PROFILE

Jan Day time	JanDT	0.04245254
Jan Peak Time	JanPT	0.016562017
Jan Night Time	JanNT	0.022688439
Feb Day time	FebDT	0.041165242
Feb Peak Time	FebPT	0.016247086
Feb Night Time	FebNT	0.022067075
Mar Day time	MarDT	0.043242586
Mar Peak Time	MarPT	0.017156093
Mar Night Time	MarNT	0.023532996
Apr Day time	AprDT	0.042090468
Apr Peak Time	AprPT	0.016507001
Apr Night Time	AprNT	0.022045653
May Day time	MayDT	0.043492642
May Peak Time	MayPT	0.0173917
May Night Time	MayNT	0.022873335
Jun Day time	JunDT	0.042008307
Jun Peak Time	JunPT	0.01694668
Jun Night Time	JunNT	0.022216509
Jul Day time	JulDT	0.044071629
Jul Peak Time	JulPT	0.017540087
Jul Night Time	JulNT	0.022885512
Aug Day time	AugDT	0.044574887
Aug Peak Time	AugPT	0.017745557
Aug Night Time	AugNT	0.023091508
Sept Day time	SepDT	0.04328619
Sept Peak Time	SepPT	0.01721052
Sept Night Time	SepNT	0.022365078
Oct Day time	OctDT	0.044778839
Oct Peak Time	OctPT	0.017999044
Oct Night Time	OctNT	0.02358635
Nov Day time	NovDT	0.044784674
Nov Peak Time	NovPT	0.017590404
Nov Night Time	NovNT	0.023063615
Dec Day time	DecDT	0.043678763
Dec Peak Time	DecPT	0.017447041
DecNight Time	DecNT	0.023613932

TABLE C.3: TECHNICAL PARAMETERS OF TECHNOLOGIES

No.	Code	Technology	Efficiency	Capacity Factor	Availability Factor	Op. Life
1	KEBMCHP00	Biomass CHP plant	38%	0.5	0.93	30
2	KECOSCP00	Coal power plant	37%	0.85	0.94	35
3	KEDSRCFI2	Diesel power plants (100kW, Industry)	35%	0.9	0.9	20
4	KEDSRCFR1	Diesel power plants (1kW, Rural, Residential/Commercial)	16%	0.9	0.9	10
5	KEDSRCFU1	Diesel power plants (1kW, Urban, Residential/Commercial)	16%	0.9	0.9	10
6	KEDSRCP03	Diesel power plants (Utility)	35%	0.9	0.9	25
7	KEGOCVP00	Geothermal power plant	100%	0.85	1	25
8	KEHFGCP00	Oil fired gas turbine OIL SCGT	35%	0.9	1	25
9	KEHYDMS01	Small hydro power plant (SHP)	100%	0.512	1	30
10	KEHYDMS02	Dam hydro power plant	100%	0.9	0.95	50
11	KEHYDMS03	Run-of-river hydro power plant	100%	0.45	0.95	30
12	KENGCCP00	Natural gas (Combined Cycle)	48%	0.935	0.93	30
13	KENGGCP00	Natural gas (Single Cycle)	30%	0.935	0.93	25
14	KESOC1P00	CSP (Without storage)	100%	0.7	1	25
15	KESOC2P00	CSP (With storage)	100%	0.7055	1	25
16	KESOC3P00	CSP (With gas firing)	48%	0.65	0.93	25
17	KESOU1P03	Solar PV (Utility)	100%	0.5		20
18	KESOV1F01	Solar PV (Roof top, Rural)	100%	0.4	1	20
19	KESOV2F01	Solar PV with storage (1 hr, Rural)	100%	0.3314	1	20
20	KESOV3F01	Solar PV with storage (2 hr, Rural)	100%	0.378	1	20
21	KESOV4F01	Solar PV (Roof top, Urban)	100%	0.4	1	20
22	KESOV5F01	Solar PV with storage (1 hr, Urban)	100%	0.3319	1	20
23	KESOV6F01	Solar PV with storage (2 hr, Urban)	100%	0.4	1	20
24	KEWI25P00	Wind (Onshore, 20% CF)	100%	0.25	0.9	20

25	KEWI30P00	Wind (Onshore, 30% CF)	100%	0.3	0.85	20
26	NUCLEAR	Nuclear Technology	33%	0.85	1	20
27	TRANS	Transmission	94.60%	1	1	60
28	DISTR	Distribution	91%	1	1	60

TABLE C.4: POPULATION PROJECTION FOR KENYA

Years	**Population**	**Years**	**Population**
	[millions]		**[millions]**
2014	44.86358		
2015	46.0503	2028	62.64336
2016	47.25145	2029	64.01964
2017	48.46693	2030	65.4119
2018	49.69532	2031	66.82006
2019	50.9355	2032	68.24376
2020	52.18672	2033	69.68224
2021	53.44786	2034	71.1345
2022	54.71882	2035	72.59958
2023	56.00127	2036	74.07677
2024	57.29775	2037	75.56544
2025	58.61017	2038	77.06465
2026	59.93879	2039	78.57342
2027	61.28311	2040	80.09073

TABLE C.5: FUEL PRICE PROJECTIONS

Years	HFO	Diesel	Natural Gas.	Coal	Uranium	Biomass
2014	14.3	17.6	5.8	3.3	1.75	2.27
2015	14.7	18.04	5.9	3.4	1.75	2.27
2016	15.1	18.92	6	3.3	1.75	2.27
2017	15.6	19.58	6.1	3.4	1.75	2.27
2018	16	20.24	6.1	3.3	1.75	2.27
2019	16.2	20.68	6.2	3.3	1.75	2.27
2020	16.3	21.01	6.3	3.3	1.75	2.27
2021	16.5	21.23	6.4	3.3	1.75	2.27
2022	16.7	21.34	6.6	3.3	1.75	2.27
2023	16.9	21.67	6.6	3.3	1.75	2.27
2024	17.1	21.89	6.6	3.3	1.75	2.27
2025	17.3	22.22	6.6	3.3	1.75	2.27
2026	17.4	22.44	6.8	3.3	1.75	2.27
2027	17.7	22.66	6.9	3.3	1.75	2.27

2028	17.9	22.99	7.1	3.3	1.75	2.27
2029	18.2	23.43	7.4	3.3	1.75	2.27
2030	18.5	23.65	7.6	3.4	1.75	2.27
2031	18.7	23.87	7.6	3.4	1.75	2.27
2032	18.8	24.09	7.6	3.3	1.75	2.27
2033	18.9	24.31	7.7	3.3	1.75	2.27
2034	19.1	24.53	7.8	3.3	1.75	2.27
2035	19.4	24.75	7.8	3.2	1.75	2.27
2036	19.5	24.97	8	3.1	1.75	2.27
2037	19.6	25.19	8.1	3.1	1.75	2.27
2038	19.9	25.41	8.3	3	1.75	2.27
2039	20	25.63	8.5	3	1.75	2.27
2040	20.1	25.85	8.5	3	1.75	2.27

Appendix D

Reference energy system:

Network of lines represent the fuels while blocks represent energy producing, transforming and consuming technologies.