ZAMBIA'S ENERGY MIX BY THE YEAR 2050

BY

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A Dissertation Submitted to the University of Zambia in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Renewable Energy Engineering

UNIVERSITY OF ZAMBIA

LUSAKA

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DECLARATION

I, PERCY KAELA, declare that am the author of this dissertation and that all the content is my original work, unless where otherwise credited. The dissertation is been submitted for the partial fulfillment of the requirement for award of the degree of Master of Engineering (Renewal Energy Engineering) at University of Zambia and has not been presented before for an award of a degree or diploma at any other institution

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APPROVAL

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ABSTRACT

In 2015 unparalleled energy crisis was experienced due to depleted energy stocks in the hydroelectric dams and reduced river flows in the Kafue and Zambezi river basin and the northern water circuit. In the past, energy profile of Zambia showed serious imbalance due to over dependence on one single source of primary energy (Hydropower). To avoid possible repeat of the energy deficit, alternative scenarios which are views of the future have been used to explore the implication of different set of assumptions to determine the degree of robustness of possible for future energy production and consumption. This study models the performance of electric energy, that would be supplied from primary energy source available within Zambia based on selected energy scenarios, for the year 2050, taking 2015 as a base year. Data regarding the characteristic of primary energy supply potentials available within the country and key drivers of final energy demand were collected. The Long-range Energy Alternatives Planning system (LEAP) tool a widely used software tool for energy mix system modelling, policy analysis simulation and climate, and was applied to three alternative scenarios for the year 2050. In this study primary energy supply options for all 2050 energy mix scenarios is hydro, coal, solar, biomass (bagasse), geothermal and wind energy. The final electric energy demand increases between 6.5 to 12.5 with a concomitant primary energy supply increment of between 7 to 16 times by 2050 in all scenario.

Key words; LEAP Tool, modelling, primary energy mix, scenarios, demand and supply.

DEDICATION

I dedicate this dissertation to my Lord almighty and his only son Jesus Christ for preserving my life and keeping me in good health during this period of reading and writing this dissertation. Am also dedicating this work to my children. I have lead by an example, that through hard work you get something and in whichever life endeavors you take, remember that through hard work you can be who want to be.

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ABBREVIATIONS

LEAP	Long-range Energy Alternatives planning
KWh	Kilo Watt Hours
MWh	Mega Watt Hours
TWh	Tara Watt Hours
GWh	Giga Watt Hours
GHG	Greenhouse gas
EDF	Electric de France
GPD	Gross Domestic Product
SADC	Southern African Development Community
HFO	Heavy Fuel Oil
IPPs	Independent Power Producers
IPCC	Inter-governmental Panel on Climate Change
MENA	Mediterranean North Africa
OECD	Organization for Economic Co-operation and Development
WEC	World Energy Council
PSDMP	Power System Development Master Plan
JICA	Japan International Corporation Agency
MCL	Maamba Collieries Limited
GSD	Geological Survey Department
CBM	Coal Bed Methane
OPPPI	Office for Promoting Private Power Investment
GHI	Global Horizontal Irradiation
ZDM	Zambia Meteorological department
MSW	Municipal Solid Waste
SEI	Stockholm Environment Institute
REA	Rural Electrification Authority

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CHAPTER ONE: INTRODUCTION

1.1 Introduction

This chapter outlines the background, motivation for this project and provides the objective of research. Further, a general overview of primary energy resources and supply is briefly outlined, research hypothesis, scope and limitation, and how this dissertation will be presented.

1.2 Background

In the recent past, energy production in many countries has been diversified by introducing alternative and renewable energy sources. There are both economic and environmental reasons that support the move toward an energy mix, which typically consists of a combination of fossil fuels, nuclear energy, and renewables. Firstly, concerns about the finite nature of conventional energy sources, such as oil and gas, and increasing global demand for energy create an economic incentive to find new ways for energy generation mix. Energy. Secondly, increased understanding of climate change and its underlying causes—mainly greenhouse gas (GHG) emissions—creates urgency for action in order to mitigate the negative impacts related to carbon-emitting fuels.

Economies worldwide are highly dependent on energy after they have been built according to the planning principles of modernization. Globally energy forecasts indicate that energy use is expected to increase for several decades to come. Society utilizes all forms of primary energy after its conversion into heat and electrical energy. China and France both have unique energy profile and industry development based on the availability of natural energy resources, and the balance of the energy production and consumption. For these ambitious countries like (China and France) achieving economic prosperity is one of the means to restore historical world leadership (Zhao, 2013). As a result energy security and development, which are the basis for economic development have remained the top priority on the agenda of both governments.

In 2006, Electric de France (EDF) worked an installed capacity of 98.19GW or 84.6 percent of the national capacity, of which 63.13GW were nuclear, 20.44GW hydro and 14.62GW fossil fired. In the same year electricity generation was 490.80TWh of which 428.10 where nuclear, 21.10TWh fossil fired and 41.60TWh hydro (Zhao, 2013). This shows that there must be an energy mix from all the available primary energy resources for electricity generation in order achieve and sustain any meaningful development.

Africa’s energy sector is vital to its future development and yet remains one of the most poorly understood regions with the global energy system (Africa Enegy Outlook , 2014). According to the International Energy Agency special report on Africa, every advanced economy is required secure access to modern energy to underpin its development and growing prosperity. Modern, high quality and reliable energy provides services such as lighting, heating, transport, communication and mechanical power that support education, better health, higher incomes and all-round improvements in the quality of life (Escribano & Pena, 2010). Africa’s energy sector is crucial to its future development because it remains one of the most underdeveloped regions within the global energy industry. However, sustained political will is essential to change energy trends for the better. The strong growth of renewable energy in many countries has raised their share in the global power generation (Africa Enegy Outlook , 2014). African countries more generally are endowed with abundant renewable energy potential, which they can harness so that, by 2040, renewables provide more than 40 percent of all power generation capacity in the region, varying in scale from large hydropower dams to mini- and off-grid solutions in more remote area (Africa Enegy Outlook , 2014).

Sub-Sahara Africa has yet to conquer the challenge of energy poverty. But the barriers to doing so are surmountable and the benefits of success are immense. The sub-Saharan economy has more than doubled in size since 2000 to reach $2.7 trillion in 2013. Yet, even after such strong growth, the economic output of the almost 940 million people in sub-Saharan Africa in 2013 remains significantly below that of the 82 million in Germany. Recent sub-Saharan economic growth can be attributed to a variety of factors, including a period of relative stability and security, improved macroeconomic management, strong domestic demand driven by a growing middle class, an increased global appetite for Africa’s resources, and population growth and urbanization (International Energy Agency, 2015). Businesses in sub-Saharan Africa most frequently cite inadequate electricity supply as a major constraint on their effective operation. It is a widespread problem that affects both countries with large domestic energy resources and those that are resource poor. Insufficient and inferior power supply has a large impact on the productivity of African businesses (Escribano & Pena, 2010).

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. On a more positive note, about 145 million people gained access to electricity since 2000, led by Nigeria, Ethiopia, South Africa, Ghana, Cameroon and Mozambique (International Energy Agency, 2015). The picture in the Southern Africa sub-region is skewed by the unique situation of South Africa at around 85 percent. South Africa has the highest electrification rate on mainland sub-Saharan Africa (International Energy Agency, 2015).The 15 SADC member states exhibit a wide diversity of demographic and socio-economic characteristics. With a population of just over 298 million, SADC accounts for approximately 32 percent of sub-Saharan Africa's total population of 926 million. Three countries – the Democratic Republic of Congo (DRC), South Africa and Tanzania – together account for more than 60 percent of the region's population. Average regional population growth, at 1.88 percent, is relatively low by developing country standards. The relative contribution to GDP of key economic sectors also varies widely, but some similarities exist. The service sector dominates in most SADC countries such as Botswana, Namibia, Seychelles and South Africa which all contribute more than 60 percent of GDP. In Zambia, by comparison, the mining sector contributes more than 50 percent of GDP, a function of the country's dependence on mineral production (Renewable Energy Policy Network for the 21st Century (REN21), 2015).

Zambia's current energy sources include electricity, petroleum, coal, biomass and other renewable energy. The country imports all its petroleum products as commingled petroleum feedstock or as finished products while electricity and other sources are mainly generated locally. According to the Ministry of Finance, the economy has been growing at an average of 5 percent per annum over the past 10 years and demand for energy has also been rising. In particular, over the last decade, electricity demand has been growing at an average of about 3 percent per annum mainly due to the increased economic activities in the country especially in the agriculture, manufacturing and mining sectors. The country's rapid economic growth has consequently led to a rising demand for energy products and services including alternative sources of energy such as solar. Zambia's electricity generation mix is dominated by hydro generation which accounts for more than 90 percent. The electricity generation mix is comprised of hydro, diesel, thermal, solar and Heavy Fuel Oil (HFO). The hydro generation mix comprises major and mini power stations. ZESCO owns the bulk of the generation stations while the rest are owned by Independent Power Producers (IPPs) (Energy Regulation Board, 2015). Zambia is not spared from the inadequate electricity supply. According to 2016 African economic outlook for Zambia the electricity crisis was among the reasons attributed to the 2015 economic headwinds which saw the country's real economic growth fall to 3.7 percent the lowest in 15 years (International Energy Agency-African energy outlook 2016, 2016).The economic development of Zambia depends on the energy self-sufficiency of the country because we are in an era whose societal advancement is based on energy. According to the central statistical office, the country's population is projected to over 15million people in 2015 (Central statistical Office, 2012).The economic growth of about 7.7 percent seen before 2013 slowed down due to international headwind as results of decelerating growth in China and the turnaround in US and European economies. The electricity supply deficit that began in mid-2015 also caused production in manufacturing, agriculture and other business to decline (Rasmussen, 2016).This under pins the fact any attempts by governments in framing economic plans and policies and plans should go hand in hand with energy development and sustainability.

1.3 Justification of the Study

To meet energy needs, each country should use the energy available to it, in different proportions. This is what is called the energy mix. While the mix varies significantly from one country to another in many cases, globally fossil fuels account for over 80 percent of the energy mix (Planete Energies an Initiative by Total, 2015). In fact, around 86 percent of Zambia's electricity is generated from these fuels types, with 73 percent from coal and 13 percent from natural gas. Around the world it's much the same, with fossil fuels being used for electricity, heating and powering vehicle (Austrilian Energy Regulator, 2014). Fortunately, for Zambia renewable energy accounts for well over 90 percent primary energy resource. Despite the country been endowed with a lot of primary energy within its borders, there has been a huge share of energy deficient in the last three year prompting a lot of outcry and the need for quick solution in order to turn back the wheels of economic and social development. The shift in the hydrological performance has affected hydropower in the last 3 year due to the fact that major Zambia's hydro power plant are located in the southern region which generally receives less rainfall. Thus hydropower in Zambia has shown that it is susceptible to hydrological changes and the ostrich strategy is no long acceptable.

To foster sustained economic and social developed, the country needs to diversify its energy mix. It is intended that this study will help unlock some of the salient issues on the subject matter.

1.4 Hypothesis

This dissertation aim to come up with the Zambia's primary energy profile mix in the year 2050, which is sustainable This will be done by Energy modeling through constructing a number of scenarios and testing them so as to better understand the country's energy road map up to 2050.

1.5 Statement of the Research Problem

In 2015 unparalleled energy crisis was experienced due to depleted energy stocks in the hydroelectric dams. Decade's earlier energy profile of Zambia reviewed serious energy imbalance due to the over dependence on a single source of primary energy (Hydropower). It is imperative that long term alternative primary energy mix is investigated, targeting the middle of this century (2050) using scenario planning approach to avoid a repeat of previous energy crisis.

1.6 Research Objectives

The main objective of this research was to analyzing the primary energy source available in the country in the year 2050 and relate to the dynamics in demand. The following were sub objectives:

1. To establishing the optimal energy mix by 2050 using scenario analysis that is Realistic scenario, Waste scenario and best scenarios taking the 2015 as a base year.
2. To mitigate against the recurrence of major energy crisis like (2014-2016).

1.7 Research Questions

1. What are the quantities of primary energy in Zambia's territory now and in future?
2. What is the total energy which can be realized from the primary energy by 2050?
3. How can energy be diversified and relate to the demand in the year 2050?

4. What is the most efficient way of utilizing the available energy sources?
5. How can mitigation measures against future energy crisis be achieved?

1.8 Scope and limitation

This study did not concentrate on the Africa or regional energy mix spectrum, rather, it specifically investigated the primary energy available within the borders of Zambia .The study focused on the primary energy sources transformation to the final energy carrier (electricity) used mostly in industrial application and home consumption.

Primary energy source from imports such as diesel and heavy fuel oil (HFO) fuels used to generate electricity and other petroleum product in transport industry will not be part of the study. The investigation of the energy mix in the era of climate change was put aside and only dedicated to the key drivers of the energy mix outlook for the year 2050 through modeling different scenarios.

1.9 Dissertation Outline

This Chapter considered the energy background from the global perspective, and narrowed the discussion to Africa, Southern African and Zambia, in particular. Chapter 2 bring out the literature review of the research subject. Chapter 3 discusses the methodology used in the investigation while chapter 4 chapter presents the results from Leap tool software model .Emerging issues from the results are analysis analyses and discussed in chapter 5. Chapter 6 outlines the conclusion and recommendation on this study**.**

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In this chapter, a general review of the literature relating to the energy mix and demand, and primary energy sources supply are presented. The chapter then focuses on energy scenarios and energy mix with a short overview of models used in energy modeling and simulation.

2.2 Energy trends

According to the IPCC, the main goal of all energy transformations is to provide energy services that improves quality of life i.e. health, life, expectancy and comfort and productivity. A supply of secure, equitable, affordable and sustainable energy is vital to future prosperity (United Nations, 1997). Approximately 45 percent of final consumer energy is used for low-temperature heat (cooking, water and space heating and drying), 10 percent for high temperature industrial process heat, and 15percent for electric motors, lighting and electronics and 30percent for transport. Demand for all forms of energy continue to rise to meet expanding economies and increase in world population. Energy supply is intimately tied in with development in broad sense (Metz, 2007).The United Nations has set millennium development goals to eradicate poverty, raising living standards and encourage sustainable economic and social development.

Zambia faced economic headwind not only due to China slow down and poor rainfall pattern but also due to electricity crises which resulted in the real economic contraction to its lowest in 15 years, with gross domestic product (GDP) growth estimated to have slowed to 3.7percent from 5percent and more than 8percent the previous years (IEA, 2016). Productivity in mining, manufacturing, agriculture and other business was greatly affected due to the massive load shedding the country was experiencing. This dissertation investigation, aims at bringing to the fore the need for energy mix in order to mitigate against a repeat of the 2015-2016 energy crisis (Rasmussen, 2016).

There are risks to being unprepared for future energy-supply constraints and disruptions. Currently fossil fuels provide almost 80percent of the world energy supply; a transition away from traditional use to zero- and low carbon-emitting modern energy system(including carbon dioxide capture and storage, as well as improved energy efficiency would be a solution to GHG emission reduction (United Nations, 2009).It is yet to be determined which technologies will facilitate this transition and which policy will provide appropriate impetus, although security of energy supply, aligned with GHG reduction goals, are co-policy drivers for many nations wishing to ensure that future generations will be able to provide for their own wellbeing without their need for energy services being compromised (Metz, 2007).

Although the technology and the policy to facilitate transition to GHG reduction is yet to be determined, this research tried to explore the different primary energy resource available to Zambia and carry out an energy diversification mix through modeling of the future energy situation.. The primary energy sources as identified by Intergovernmental Panel on Climate Change are as shown in Figure 1.

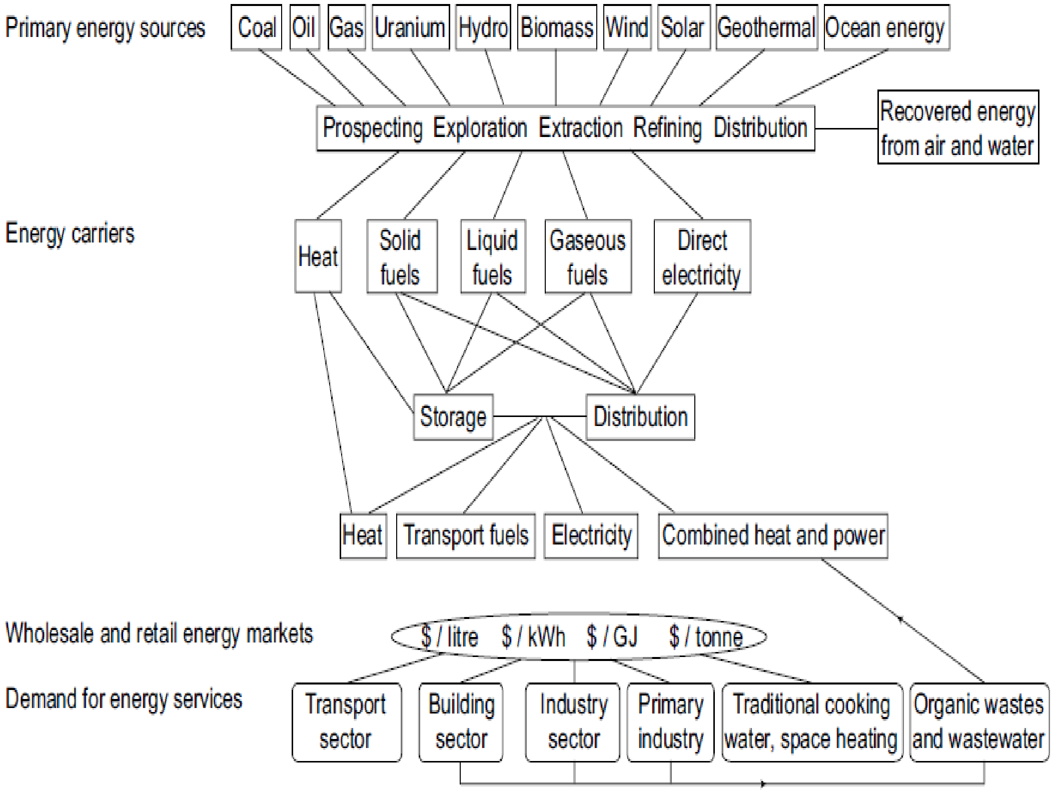


Figure 1: ***Complex interactions between primary energy sources and energy carriers***

Source Energy supply chapter 4 IPCC Report (2009)

Providing energy services from a range of sources to meet society's demand should offer security of supply, be affordable and have minimal impact on the environment. Primary energy sources are:

fossil carbon fuels; geothermal heat, fissionable, fertile and fissionable nuclides; gravitational (tides) and rotational forces (ocean current) and the solar flux. These must be extracted, collected, concentrated, transformed, transported, distributed and stored if (necessary) using technologies that consume some energy at every step of the supply chain. Energy carriers such as heat, electricity and solids, liquid and gaseous fuels deliver useful energy services. The conversion of the primary energy to energy carriers and eventually to energy services creates losses, which, together with distribution losses, represent inefficiencies and cost of delivery (Metz, 2007).

The changes in energy over the past 20 years have been significant (World Energy Council, 2013). Analysis of energy supply should be integrated with energy carriers and end use since all these aspects is inextricably and reciprocally dependent.

2.3 Energy Mix Scenarios

Scenario can be defined as *a* "generally intelligible description of a possible situation in the future, based on complex network of influence factors" (Sartas, November 2006). Scenarios are alternative views of the future which can be used to explore the implication of different set of assumptions and to determine the degree of robustness of possible future development (World Energy Council, 2013). In the evaluated alternative future energy mix for Brazil, three scenarios for an energy mix model were used (Coelho, 2001). In this study, a similar approach will be used to study for the 2050 energy mix.

In order to achieve self-sufficiency in electricity generation and become more independent of the fluctuating and rising price of oil, the government of Guatemala developed the Electricity Generation Expansion Plan 2008-2028, which was recently updated to cover the period 2014-2028. It was part of a strategy to upgrade the whole electricity system in the country. (Ochaeta, 2014). The Expansion Plan's objectives, which are in line with the country's energy policy goals, are: diversification of energy mix, increasing the installed capacity of renewable sources to at least 67.5percent (Ochaeta, 2014). Denmark used scenario-building project techniques to explore the future energy system. The scenarios developed differing options and combinations of options. Two key targets formed the scenarios (Alhamwi, 2013):

1. To reduce the use of oil in 2025 by 50 percent compared to the 2003 base-line.
2. To reduce the emissions of CO2 in 2025 by 50 percent compared to the 1990 base-line.

The focus was on technology-based scenarios and described what kind of technological energy mix could be used to achieve these main targets. In all, the task force group prepared four technology scenarios, each exploring a different energy system designed to meet the targets. (Alhamwi, 2013).

In North Africa, the renewable power generation aggregated across the region shows a dynamic behavior (Alhamwi, 2013). Hence, in a future (Mediterranean North Africa) MENA region with a very high share of renewable power generation and consequently a highly dynamic power generation behavior, an optimized power technology mix is needed to counterbalance each other to be able to follow the seasonal load curve as good as possible and to avoid the construction of renewable power overcapacities and non-efficient use of storage devices that could be simply avoided with a meteorological pre-planning (Alhamwi, 2013).

Energy scenarios are used to assess the impacts of different developments under assumptions of certain outcomes. Scenarios should not be confused with policy prescriptions or the likelihood of outcomes, rather they can be used as an aid mapping of different energy futures. Based on energy models, different types of energy scenarios can be constructed, using the techniques of forecasting and back casting (World Energy Council, 2013).

Randall et al. conducted a study for southern Africa, whose objective was to analyze and provide projections of electricity supply and demand for over a long time period (2010–2070), based on a set of internally consistent development scenarios, and using bottom-up demand analysis. In addition, the analysis combines a simulation of the stated expansion plans of the national electricity utility based on identified energy potential (Spalding-Fecher, 2016). Similar approach is adopted for this study with time horizon of 2015-2050.

2.4 Review of Issues from Energy Mix Scenarios

Energy mix scenarios can be used to study energy technology mix in addition to other associated targets in various studies. The investigation for energy mix is one of the main techniques for evaluation of alternatives for energy projection on the national as well as regional scale (Spalding-Fecher, 2016). In this study, similar approach for Zambia's energy mix for 2050 is adopted. Energy mix scenarios are a tool for energy policy options that a country can use to arrive at the future preferred energy situation. Three scenarios shall be build and tested in the methodology to answer the future energy outlook for Zambia in the year 2050. From the literature, it is agreeable that energy road map is best constructed using scenarios.

2.5 Energy Modeling

Today's global patterns of energy supply serve the needs of concurrent energy markets. Answering concerns about our future energy demand and supply requires that we utilize theory, tools and models, on the basis of which we imagine a vision of the future and formulate a strategy to establish the desired energy mix that is suitable for the anticipated future. Several classification can be used to distinguish among used models for formulating a strategy for future energy mix and the following are the approaches (Weijermars, 2011).

1. Forward projection of the past econometric trends
2. Scenarios unconstrained by quantitative models
3. Specific energy market equilibrium models
4. Mixed energy system analysis
5. Normative scenarios analysis based on energy system mode
6. Esoteric vision of our energy future

Energy modeling is considered useful because it is an efficient, feasible and necessary means of understanding complex systems. Different approaches to energy modeling can depict an overall picture of total energy demand and supply and a consistent accounting of energy resources, including imported energy as they move through the production, transformation, inventory, and consumption phases of their life cycle to help determine lowest possible costs. Modeling can provide a basis for the discussion of the nature of the problem, and if the model assumptions are expressed in an untestable form, also comparisons between different approaches can be made and their validity discussed (Thomas & Unger , 2010).

In both energy policy and energy-modelling, the role of assumptions cannot be ignored. In scientific practice, assumptions manifest in relation to the worldview and theories that underpin energy model-making (Heinonen, 2014).

In the modeling of the energy sub-system, bottom-up energy models, or partial equilibrium models, can be divided into supply-side and demand-side models. In bottom-up modeling, energy demand is treated as given parameter, which helps in the optimization of the energy system (Spalding-Fecher, 2016).

In the energy sector, energy models have also been used as a basis for investment plans, legislation and regulation (Thomas & Unger , 2010). A model needs to be able to account for all the factors affecting the system to provide a useful schema of reality. Models can be used for mapping or exploring and are typically used for the aim of policy-making. Typically, energy models have been employed to depict the future energy demand and supply of a country or a region (Andrea, 2012).

Energy models have been employed as tools to improve energy systems and energy infrastructure across industrialized countries. The emergence of macroeconomic energy models in the 1950s largely coincides with the need to develop the industrial economy. Detailed techno-economic models were then developed in the early 1970s as a response to the oil crisis (Centre for Future Research, 2014).Understandably, energy models have conventionally modeled the technical features of the energy system, and in linkage with the national economy. Still today, they have considerable normative influence (Centre for Future Research, 2014).

2.6 Review of Energy Modeling

In developing countries, searching for optimal development paths, energy futures and infrastructure are yet to shape. Therefore, alternative energy modeling and scenario building could serve as powerful tools. The bottom up approach to determine demand attributed above is what will be implemented in this study as opposite to general subsystem demand calculation. The demand linked to key drivers is what will reflect realistic demand determination in energy modeling.

2.7 Energy Demand

Population growth and increase in income per capita has always been and will remain key drivers behind growing demand for energy (World Energy Council, 2013). By 2035, the world’s population is projected to reach 8.7 billion, which means an additional 1.6 billion people will need energy. Over the same period, GDP is expected to be more than double, with non OECD contributing nearly 60 percent growth. Globally, GDP per capita in 2035 is expected to be 75 percent higher than today, an increase in productivity which account for three quarter of the global GDP growth. Primary energy consumption shall increase by 37 percent between 2035, with growth averaging 1.4percent p.a. virtually (96percent) of the projected growth is in the non OECD with energy consumption at about 2.2percent (BP plc, 2015). This on the other hand reflects the end of the phase of rapid growth in energy demand in developing Asia centered on China, driven by industrialization and electrification.

A model for peak load demand should take into account the following factors or part of them, depending on the country in which the model is to be implemented. These factors are;

- The gross domestic product
- The population (POP)
- The GDP per capita(GDP/CAP)
- The multiplication of electricity consumption by population (EP)
- The power system losses (LOSS)
- The load factor (LF)
- The cost of one Kilowatt-hour(US/kWh)

The first four factors depend on the behavior of the public whereas the last three are depend on the electric power system and the load itself. Therefore a numerical load forecast demand model can thus be written as (Elsevier Inc., 2010):

$P_L = f(GDP)+g(POP)+h(EP)+k(GDP/CP) + i\ (LOSS) +j\ (LF) +m\ (US/kWh)$…………………2.1

2.8 Review of Issues from Energy Demand

Population growth and increase in income are expected driver to be behind Zambia’s energy demand in 2050. As can be seen in the Figure 3 the projected population is expected to grow from 13.7 million to 17.8 million in 2020 and 26.9 million by 2035 according to population projection report by central statistics office (Central Statistical Office, July 2013). It is reasonable to assume that the projected population growth will be in tandem with the appropriate GDP growth rate. In this project, the population will have almost doubled yet the population growth rate used was 2.8 percent which assumed little changes.

In econometrics and management science, the relationship between Energy mix and Gross domestic product (GDP) were explored by means of a panel model with energy mix summaries. The result of his study showed that strong relations exist between variable proxy for the total per capita consumption, the technological development levels, international position and the utilization of energy (Zeeuw, 2014). The other factors contributing to the demand are the degree of electrification measured in terms of share of electricity on the final energy (World Energy Council, 2013) or said in another way multiplication of the energy consumption by population, energy system losses and the load factor for energy conversion facilities and or power plants.

The government of Zambia has expressed interest to increase electrification from 25 percent to about 66percent total electrification by 2030 in the national energy policy of 2008. This shall result in 90percent urban and 50percent rural electrification (Ministry of Energy and Water Development, 2008).

Long-term final energy (electric) load forecasting is an important issue in effective and efficient planning. The growth in electricity consumption in many developing countries such as Zambia has outstripped existing projections, and accordingly, the uncertainties of forecasting have increased. Variables such as economic growth, population, and efficiency standards, coupled with other factors inherent in the mathematical development of forecasting model, make accurate projections difficult (Elsevier Inc., 2010).

In Zambia, the total energy consumption by sector during 2010 to 2015 is shown in the Table 1. The econometric approach above combines economic theory and statistical technique for forecasting electricity demand. This approach estimates the relationship between energy consumption (depended variables) and factors influencing consumption in the econometric model such as residential, commercial, industrial, mining, agriculture etc. (Kalantar, 2011).

Table 1: Energy MWh Consumption by sector.

SECTORS	YEAR 2011	YEAR 2012	YEAR 2013	YEAR 2014	YEAR 2015
OTHERS	299,004	140,732	126,035	108,056	98,494
AGRICULTURE	193,692	226,890	238,310	265,338	260,426
QUARRY	14,110	54,393	18,610	6,944	68,188
MANUFACTURING	403,787	556,273	487,682	549,188	530,772
ENERGY AND WATER	88,694	81,201	78,840	80,339	89,069
CONSTRUCTION	9,803	10,016	13,395	18,807	15,198
TRADE	144,109	143,564	133,020	117,985	109,809
TRANSPORT	21,830	22,689	24,395	34,117	33,363
FINANCE AND PROPERTY	345,862	397,167	454,531	533,514	516,927
SERVICES(HOUSEHOLDS)	2,782,896	3,021,772	3,223,394	3,567,259	3,482,025
MINING	5,050,211	5,050,211	5,751,821	5,905,003	6,220,619
TOTAL	**9,353,998**	**9,704,908**	**10,550,033**	**11,186,550**	**11,424,890**

Source ZESCO (2016)

2.9 Primary Energy Supply Options

2.9.1 Fossil Fuels

Fossil energy resources in the world remain abundant but contain significant amounts of carbon that are normally released during combustion. The proven and probable reserves of oil and gas are enough to last for decades and in case of coal, centuries. Possible undiscovered resources extend these projections even further (Metz, 2007). Fossil fuels supplied 80percent of the world primary energy demand in 2004 and their use is expected to grow in absolute terms over the next 20-30 years in the absence of policies to promote low carbon emission sources (International Energy Agency, 2014).

2.9.1.1 Coal and peat

Despite its poor environmental credentials, coal remain a crucial contributor to energy supply in many countries. Coal is the most wide-spread fossil fuel around the world, and more than 75 countries have coal deposit. The current share of coal in global power generation is over 40 percent (World Energy Council, 2013).

The supply and consumption of coal is limited to bituminous coal in Zambia. From the supply side while 244,000 tons of coal were produced domestically, 12,000 tons were exported, 61,000 tons were stocked and finally 171,000 tons were supplied for domestic use. Most of the domestic supply of 157,000 tons is for industrial use, and consumed in the copper mining, cement production and breweries (Chubu Electric Power Co., Inc, 2010).

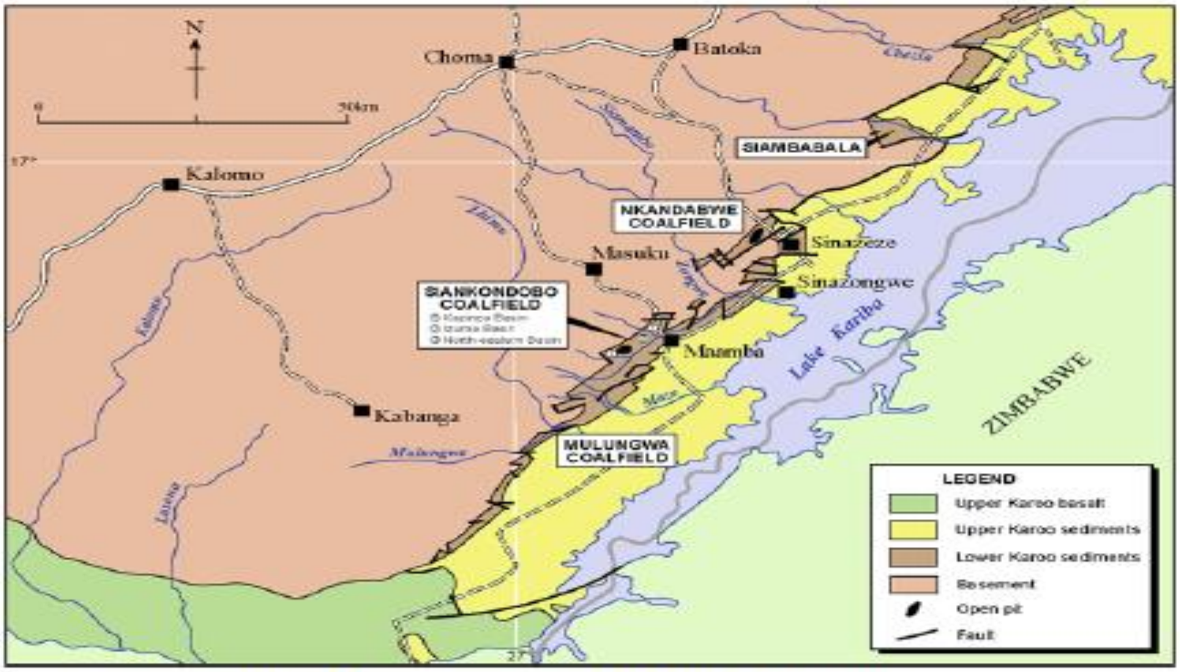
In Zambia coal mines are exclusively found in the Zambezi valley basin on the coal bearing sediment. The world energy council (WEC) estimated that the proved recoverable coal reserves in the African country is as shown on Table 2. According to WEC, while reserves in the Republic of South Africa comprises 97.7 percent of the total African coal (11 percent in the world), that in Zambia is just 10 million tons (Chubu Electric Power Co., Inc, 2010).

Table 2: Recoverable Coal Reserves at the End of 2005

S/N	Country	Bituminous including Anthracite	Sub-bituminous	Lignite	Total (million tons)
1	Botswana	40	0	0	40
2	DR Congo	88	0	0	88
4	Malawi		2	0	2
5	Mozambique	212	0	0	212
6	South Africa	48,000	0	0	48,000
7	Swaziland	208	0	0	208
8	Zambia	10	0	0	10
9	Zimbabwe	502	0	0	502

Source; modified from survey of energy resource, World Energy council (2007)0

Coal resources are found in a number of localities in Zambia and significant deposit have been discovered and mined on the mid-Zambezi valley areas of Maamba, Sinasongwe and Sinazeze. Other areas are Western Province and the Luangwa valley as shown in Figure 4 (Chubu Electric Power Co., Inc, 2010). At the end of 1996, the only major proven reserves of bituminous coal were those defined and owned by Maamba collieries-specifically 13 million tons of open pit,14 million tons of underground coal in the Izuma basin, 30 million tons of open- pit and 20 million tons of underground coal in the Kazinze basin (Chubu Electric Power Co., Inc, 2010).



(Source) Investment Opportunities in Mining Industry, MMMD, 1998

Figure 2: ***Coalfield distribution in Zambezi Valley***

As for the quality of coal in Zambia, ash content are high and the calorific values are low compared with Wankie coalfield in Zimbabwe and Witbank coalfield in south Africa as shown in the Table 3.

Table 3: Analyses of Zambian Coal ash content

Area	H_2O %	Ash %	Volatile %	Fixed C %	S %	Calorific Value kCal/kg	No. of Analyses
Zambia							
Mid Zambezi							
- Nkandabwe	2.1	23.5	22.2	53.3	1.5	5,943	1,210
- Maamba	1.8	21.4	19.0	57.9	2.21	6,233	1,625
- Sinakumbe	2.3	22.3	18.2	56.8	1.21	5,996	50
- Mulungwa	1.6	23.3	17.9	57.1	0.77	6,056	50
Western Province	7.3	17.6	29.0	46.1	2.13	5,720	
Luangwa Valley	8.0	16.4	30.4	45.7	0.46	5,744	
Zimbabwe							
Wankie	0.76	9.8	23.8	65.7		7,534	
South Africa							
Witbank	2.3	13.0	28.5	56.2	1.06	6,833	

(Source) The Geology and Mineral Resources of Zambia Memoir No.6, Geological Survey of Zambia, 2001.

2.9.1.2 Review of Issues from Coal Energy Resource

The power system development master plan (PSDMP) study carried by JICA Chubu electric power identified the location of coal in Zambia. The quantity of proven coal reverse for the mid Zambezi valley was estimated. However, the report was short of estimating the actual total quantity of coal reserves (Chubu Electric Power Co., Inc, 2010).

The central statistical office in their energy statistic reported that the quantity of proven coal reserves is 60.2 million tons. From the production statistic at Maamba Collieries Limited (MCL) a total of 5, 7772,414 tons had been extracted during the period 1990-2009.Therefore, there was a total of 58,752,734 tons of proven coal reserves at the beginning of the year 2010 (Central Statistical Office, October, 2015). If MCL is operated at its rated capacity of 800,000 tons coal productions per year, in 2050 almost 23 million tons will still be available for energy conversion to electricity.

The existence of coal in developing countries in Southern Africa(Zambia) include with electricity challenges, coal is the secure way to fuel growth in electricity supply, since it can play a major role in supporting the development of base load electricity where it's needed most. (World Energy Council, 2013). This what is expected after the commissioning of the coal fired 300MW power plant in Maamba.

2.9.1.3 Natural Gas

Natural gas fired power generation has grown rapidly since the 1980 because it is relatively superior to other fossil fuels technology in terms of investment cost.

Unconventional natural gas like methane store in a variety of geologically complex, unconventional reservoirs, such as tight gas sands, fractured shale, coal beds and hydrates, is more abundant than conventional gas. Development and distribution of these unconventional gas resources remain limited worldwide (Metz, 2007).

According to the report natural gas commercially feasibility deposit has never been confirmed so far, although inquiry is performed together with oil by Geological Survey Department (GSD). The potential for coal bed methane (CBM) in the lower Karoo measures of Zambia is yet to be investigated also (Chubu Electric Power Co., Inc, 2010).

2.9.1. 4 Review of Issues from Natural Gas

Natural gas will not be part of the study as there is insufficient literature to support the existence of this resource in Zambia (Chubu Electric Power Co., Inc, 2010).

2.9.2. Petroleum fuels

Conventional oil products from crude oil well boles and processed by primary secondary or tertiary methods represent about 37 percent of the total world energy consumption with the major resources concentrated in relatively few countries. Two thirds of the proven oil reserves are located in the Middle East and North Africa. (International Energy Agency, 2014)

Two companies, Placid Oil Company, Zambia and Mobil, have undertaken exploration works in Zambia but with negative, albeit inconclusive results (Lusaka Times, 2017).

The Phanerozoic geology of Zambia offer a number of pointers to the potential for oil. The Barotse Basin of western Zambia contains Karoo (Carboniferous-Triassic) sediment below a thin, possibly tertiary cover (Chubu Electric Power Co., Inc, 2010). In 2004 a technical committee was set up to inquire on the possibility of oil deposit following the discovery of oil by Zambia’s neighbors such as Angola, which share the same geological formation.

2.9.2.1 Review of Issues from Petroleum Energy Resource

This study assumed that this resource will not be part of the primary energy added to the 2050 energy mix due to insufficient literature to support its existence within Zambia’s borders.

2.9.3 Nuclear Energy Potential

Nuclear Energy is the use of nuclear reactions that release nuclear energy to generate heat. The heat is removed from the reactor core by a cooling system that uses the heat to generate steam, which drives a steam turbine connected to a generator producing electricity in a nuclear power station.

Uranium is the main source of the fuel for nuclear reactor. Worldwide output of uranium has recently been on the rise after a long period of declining production caused by oversupply following nuclear disarmament. The present survey shows that total identified uranium resource have grown by 12.5percent since 2008 and they are sufficient for over a 100 year supply based on current requirement (World Energy Council, 2013). Sub-Sahara African Countries includes three of the ten-largest uranium resource-holders in the world (Namibia, Niger and South Africa) (World Energy Council, 2013).

In the recent past a number of uranium projects have come up in Zambia as shown in Table 4. The notable ones are the Mutanga and Chirundu projects in southern Zambia and the Lumwana project in North western Zambia. Mutanga owned by GoviEx Uranium Inc. of Canada has come up with a measured resource of 500 tons at grade of 0.04percent uranium, indicative resource of 2,235 tons and an inferred resource of 16,000 tons (Ngulube, 2017).

Table 4: Estimated Uranium Resource in Zambia

Project	Company	Estimated Resource (tons)	Status
Mutanga	GoviEx Uranium Inc.	75.5 Million	Mining License granted
Chirundu	Africa Energy Resource	18.7 Million	Mining License granted
Lumwana	Lumwana Mining Company	6.370 Million	Mining License granted

Source:Zacharish Ngulube (2017)

2.9.3.1 Review of Issues from Nuclear Energy Resource

Depending on the type of reactor, Massachusetts Institute of Technology (2011), estimate 200 metric tons of uranium ore is required to produce a Gigawatt of electricity per year. (Ngulube, 2017).This energy source may be part of the 2050 primary energy, however its penetration in the mix will not be allocated owing to the government inertia to come up with and implement a regulatory policy frame for uranium mining.

2.9.4 Renewable Energy Potential

Renewable energy accounts for over 15percent of the world primary energy supply. Renewable Energy technologies can be broadly classified into four categories;

1. Technologically mature with established markets in at least several countries:-large and small hydros, woody biomass combustion, geothermal, land fill gas. Crystalline silicon PV solar water heating, onshore wind, bioethanol from sugar and start(mainly brazil and US)

2. Technologically mature but with relatively new and immature markets in small number of countries:-municipal solid waste to energy, anaerobic digestion, biodiesel, co-firing of biomass, concentrating solar dishes and troughs, solar assisted air conditioning, mini and micro hydro and off show wind
3. Under technological development with demonstrations or small scale commercial application, but approaching wider market introduction:-thin film PV, concentrated PV, tidal range and current, wave power, biomass gasification and pyrolysis, bioethanol from lingo cellulose and solar thermal towers; and
4. Still in technology research stage;-organic and inorganic nanotechnology solar cells, artificial photosynthesis biological hydrogen production involving biomass, algae and bacteria, bio refineries , ocean thermal and saline gradient and ocean current.

2.9.4.1 Hydropower

Even though Zambia has abundant hydropower potentials, it is only ranked eleventh in the African continent. For Zambia, per capital potential is 20percent bigger than the average of the total Africa (Chubu Electric Power Co., Inc, 2010)

The amount of rainfall in Zambia generally tends to increase as one proceeds further north. Although there is a dry season extending mainly for the months of June, July and August, parts of North western, Luapula and Northern Province receives more than 1,300 millimeters of rainfall per year (Japan International Cooperation Agency, January 2008). Topographically, Zambia is characterized by mountainous zones in the north, with high elevations in North-Western, Luapula and Northern provinces. The elevations of the vicinity of the Zambezi River downstream of Lake Kariba and Luangwa River, which flows through the eastern part of the country is less than 600 meters. As the rest of Zambia lies at an elevation of about 1,000 meters there is a big difference from those area near the aforementioned two rivers. Further, there is a watershed in Northern Province, such that rivers in Luapula and Northern provinces flow into the DRC. Those in other provinces flow southwards and ultimately into the Zambezi. Estimating the hydropower potential as far as topography is concerned from this basic information, the chief candidates would be 1) the Muchinga River and 2) the downstream of the Zambezi, whose catchment areas encompasses most of Zambia and the Kafue River and its tributary (Chubu Electric Power Co., Inc, 2010).Table 5 shows rainfall data for selected towns.

Table 5: Rainfall Data of Selected Towns

Name of station	East Longtitude	South Latitude	Rainfall (mm)	Name of station	East Longtitude	South Latitude	Rainfall (mm)
Chipata	32.58	13.57	980.4	Mansa	28.85	11.1	1179.2
Chipepo	27.88	16.8	776.5	Mbala	31.33	8.85	1202.4
Choma	27.07	16.85	770.7	Mfuwe	31.93	13.27	810.8
Isoka	32.63	10.17	1086.2	Misamfu	31.22	10.18	1330.7
kapombo	24.2	13.6	1040.6	Mkushi	29.8	13.6	1178.4
Kabwe Met	28.48	14.42	901.4	Mongu	23.17	15.25	914.4
Kabwe Agro	28.5	14.4	878.2	Mpika	31.43	11.9	993.6
Kafironda	28.17	12.63	1274.8	Msekera	32.57	13.65	1010.3
Kafue	27.92	15.77	746.3	Mtmakulu	28.32	15.55	878.2
Kalabo	22.7	14.95	807.8	Mumbwa	27.07	14.98	820.6
Kaoma	24.8	14.8	904.5	Mwinilunga	24.43	11.75	1390.4
Kasama	31.13	10.22	1309.5	Ndola	28.66	13	1185
Kasempa	25.83	13.47	1155.4	Petauke	31.28	14.25	967.8
Kawambwa	29.25	9.8	1361.9	Samfya	29.32	11.21	1478.7
Livingstone	25.82	17.82	637.1	Senanga	23.27	16.12	727
Lundazi	33.2	12.28	874.2	Serenje	30.22	13.23	1058.7
Lusaka Hq	28.32	15.42	821.5	Sesheke	24.3	17.47	627.7
Lusaka Airpor	28.43	15.32	934	Solwezi	26.38	12.18	1341.9
Lusitu	28.82	16.18	534.7	Zambezi	23.12	13.53	1022.3
Magoye	27.63	16.13	715.1				

Source: JICA Development Study for the Rural Electrification Plan in Zambia (2008)

According to power system development master plan report, a number of previous studies indicate that Zambia has a hydropower potential of about 6,000MW (Chubu Electric Power Co., Inc, 2010). However, only about 2,373.55MW of this potential have been developed. There have already been studies for the selection of promising new sites to realize the available potential.

2.9.4.1.1 Medium to Large Hydropower Potential

The hydropower sites on the main channel of the Zambezi studied to date include Batoka, Devil's Gorge and Mpata Gorges (Chubu Electric Power Co., Inc, 2010). Currently on the Zambezi River system hydropower plan have been developed at Kariba and Victoria falls. Studies are have also been made on the sites for development on the Luapula River, and Kalungwishi which flow into Lake Mweru. According to JICA study, comparatively many sites for mini-hydropower development of up 30MW in North western province exist. In terms of physical distribution the major hydropower potentials, may be divided into biggest tributary of Zambezi, the border with the Democratic Republic of Congo and northern region, and the hilly region containing the Muchinga Escarpment to the west of south Luangwa National park (Chubu Electric Power Co., Inc, 2010). Table 6 shows hydropower potential for various sites.

Table 6: Hydropower Potentials for Various Sites

No.	NAME OF SITE	TOTAL CAPACITY (MW)	RIVER
1	KABOMPO GORGE	40.00	KABOMPO
2	KABWELUME FALLS	96.00	KALUNGWISHI
3	KUNDABWIKA FALLS	151.00	KALUNGWISHI
4	CHAVUMA FALLS	14.00	ZAMBEZI
5	CHANDA FALLS	1.00	KASHIJI
6	NGONYE FALLS	40.00	ZAMBEZI
7	MUCHINGA	230.00	LUNSEMFWA
8	LUCHENENE	34.00	LUCHENENE
9	MUTINONDO	43.00	MUTINONDO
10	MULEMBO/LELYA	330.00	MULEMBO
11	MAMBILIMA FALLS I	126.00	LUAPULA
12	MAMBILIMA FALLS II	202.00	LUAPULA
13	MAMBILIMA FALLS V	372.00	LUAPULA
14	MUMBOTUTA FALLS	490.00	LUAPULA
15	BATOKA GORGE	1,600.00	ZAMBEZI
16	DEVIL'S GORGE	1,000.00	ZAMBEZI
17	MPATA GORGE	543.00	ZAMBEZI
18	KAFUE GORGE LOWER	750.00	KAFUE
	Total (MW)	**6,062.00**	

Source: OPPPPI status report at September 30 (2015)

The total potential from Table 6 was used in this research to simulate how the power plants will be added to the power system between 2015 and 2050, once they have been developed in order to meet Zambia’s demand.

2.9.4.1.2 Small scale Hydropower

Zambia has a number of potential sites on small rivers suitable for local small-scale power generation. As stated earlier, most promising sites for such development are in North- Western and Northern parts of the country, due to the topology of the terrain, the geology of the ground and high annual rainfall. Table 7 shows the small scale hydropower potential in Zambia.

Table 7: Small Scale Hydropower Potential

No.	River Basin	Site	River	Capacity (kW)
1	Zambezi	Zambezi Falls	Zambezi	To be determined
2	Zambezi	Chavuma Falls	Zambezi	10-20,000
3	Zambezi	Sachibondo	Luakela	600
4	Zambezi	Mwinilunga	West Lunga	2500
5	Zambezi	Kapembe	Kabompo	To be determined
6	Zambezi	Chikata Falls	Kabompo	3000
7	Kafue	Kasempa	Lufupa	230
8	Kafue	Mutanda	Lunga	400
9	Kafue	Kelongwa	Lunga	To be determined
10	Chambeshi	Chandaweyaya	Chambeshi	To be determined
11	Chambeshi	Mbesuma	Chambeshi	To be determined
12	Chambeshi	Shiwang’ndu	Manshya	1,000

Source National Energy policy, (2008), originally from CEEEZ limited (2004)

In this research the small hydropower site potential were combined and represented as other hydropower plants so that the amount of data to be entered could be reduced for modelling purposes.

According to the OPPPI status report of 2015 the installed hydropower plants are as shown in the table in Table 8. The plant capacities in table 9 will modelled as exist plant and relate to the demand. The changes in demand will call for more plants to be added to the power system until the year 2050.

Table 8: Existing Hydropower Stations

No.	Power Station	Owner	Installed Capacity (MW)
1.	Kafue Gorge	ZESCO	990
2.	Kariba North Bank	ZESCO	1080
3.	Victoria Falls	ZESCO	108
4.	Lunzua	ZESCO	14.8
5.	Lusiwasi	ZESCO	12
6.	Chishimba Falls	ZESCO	6
7.	Musonda Falls	ZESCO	5
8.	Lunzua	ZESCO	0.75
9.	Shiwa Ng'andu	ZESCO	1
10.	Lunsemfwa	LHP Ltd	31
11.	Mulungushi	LHP	25
12.	Itezhi-Tezhi	ZESCO	120
	TOTAL		2,273.55

Source OPPPI status report at September 30 (2015)

2.9.4.1.3 Review of Issues from Hydropower Resource

From the Table 8, it is clear that the primary energy resource in terms of hydropower has not been exploited to the fullest since only about 2300MW of the available 8500MW has been exploited. The country still has well over 6000 megawatt hydropower potential which can be mixed with other energy source.

The Itezhi-Tezhi hydropower project consisting 2 unit of 60MW generated started construction from 2009 and subsequently commissioned in 2015 (Japan International Cooperation Agency, January 2008) and in the same year construction of the Kafue gorge lower project was initiated such that at the completion of the plant in 2020 the Kafue river basin hydropower potential will be fully realized.

The literature in the power system development master plan does not show the updated potentials for some sites and the estimate for the total hydro potential has changed significantly. Further ZESCO limited which owns and operate most of the power stations in Zambia is in the process of rehabilitating and uprating the existing small hydro after the completion of the rehabilitation of their larger hydro power station. In Luapula, Musonda, fall power station which currently has installed capacity of 5MW will be up graded to 10MW and this plant is likely to be commissioned in the first quarter of 2018 (Energy Regulation Board, 2015). At Chishimba falls the power plant will also up graded to 10MW. However, the rehabilitation works are yet to be commissioned. The Lusiwasi site will be split in two power stations, Lusiwasi upper and Lusiwasi lower. The combined capacity of the two plants will about 120MW once completed.

In the analysis of the energy system modeling, power station that are under construction will be added to the energy mix in the expected year of commissioning. For example 10MW power from Musonda Falls will be added to the power system in 2018 and 750MW from Kafue Gorge Lower power station will be added to the power system in 2021 respectively. Other plants whose commissioning date is not known will be added automatically according depending on the demand.

In order to narrow the scope of the analysis the Pico and micro hydros will not be added to the energy mix since this will be supported by the grid extension work being carried out by Rural Electrification Authority.

2.9.5 Solar Energy Potential

The interactions of extra-terrestrial solar radiation with the Earth's atmosphere, surface and objects are divided into four groups

i) Solar geometry, trajectory around the sun and Earth's rotation (declination, latitude, solar angle)
ii) Atmospheric attenuation (scattering and absorption) by: Atmospheric gases (air molecules, ozone, NO_2, CO_2 and O_2) put the 2 as a sub script Solid and liquid particles (aerosols) and water vapor Clouds.
iii) Topography (elevation, surface inclination and orientation, horizon)
iv) Shadows, reflections from surface or local obstacles (trees, buildings, etc.) and re-diffusion by atmosphere.

The atmosphere attenuates solar radian selectively, some wavelength area associated with high attenuation and others with good transmission. Small part of the radiation reflected by the atmosphere and which reaching an inclined plane is called the reflected radiation (World Bank Group, 2014). Figure 3 shows interaction of solar radiation with atmosphere and surface.

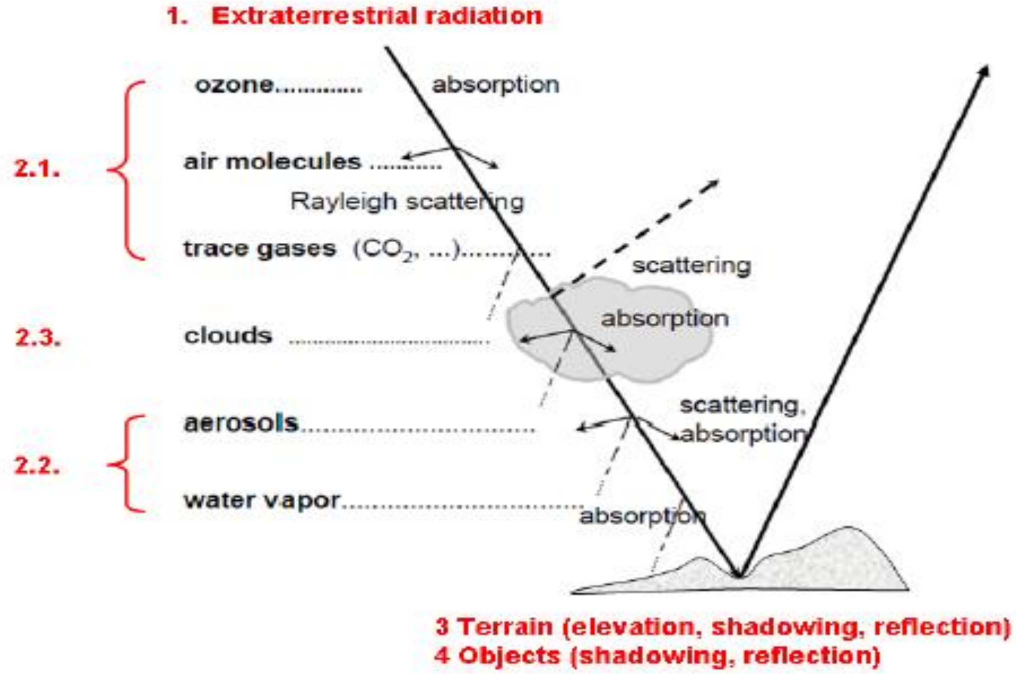


Figure 3***: Interaction of solar radiation with the atmosphere and surface***

Source; Solar modelling report, World Bank (2014)

2.9.5.1 Global horizontal irradiation

Global horizontal irradiation is often considered as a climate reference as it enables to compare individual site or regions. Solar resource is well distributed across Zambia. The most important parameter for Photovoltaic power evaluation is the Global Tilted irradiation (GTI) i.e. the sum of direct and diffuse solar radiation failing on the tilted surface of PV modules. Direct normal irradiation is relevant for solar thermal power plant (CSP) and photovoltaic concentrating technologies (CPV). In Zambia the Global horizontal Irradiation is distributed as shown in the Figure 5. In Zambia the highest GHI is identified in the south west part of the western province and south east part of Luapula province, where daily sums reach 6.3kWh/km2 (year sum about 2300kWh/km2. Season of the highest irradiation last for a period of four month starting from August up to November (World Bank Group, 2014).

2.9.5.2 Photovoltaic Power Potential

The map of potential power output presents theoretical potential power production of a PV system installed with mainstream technology configuration as shown in Figure 4. The reference configuration for PV potential is a PV system with crystalline-silicone models mounted in a fixed position on a table facing north and inclined at an angle closed to maximum at which yearly sum of global tilted irradiation received by PV module is maximum.

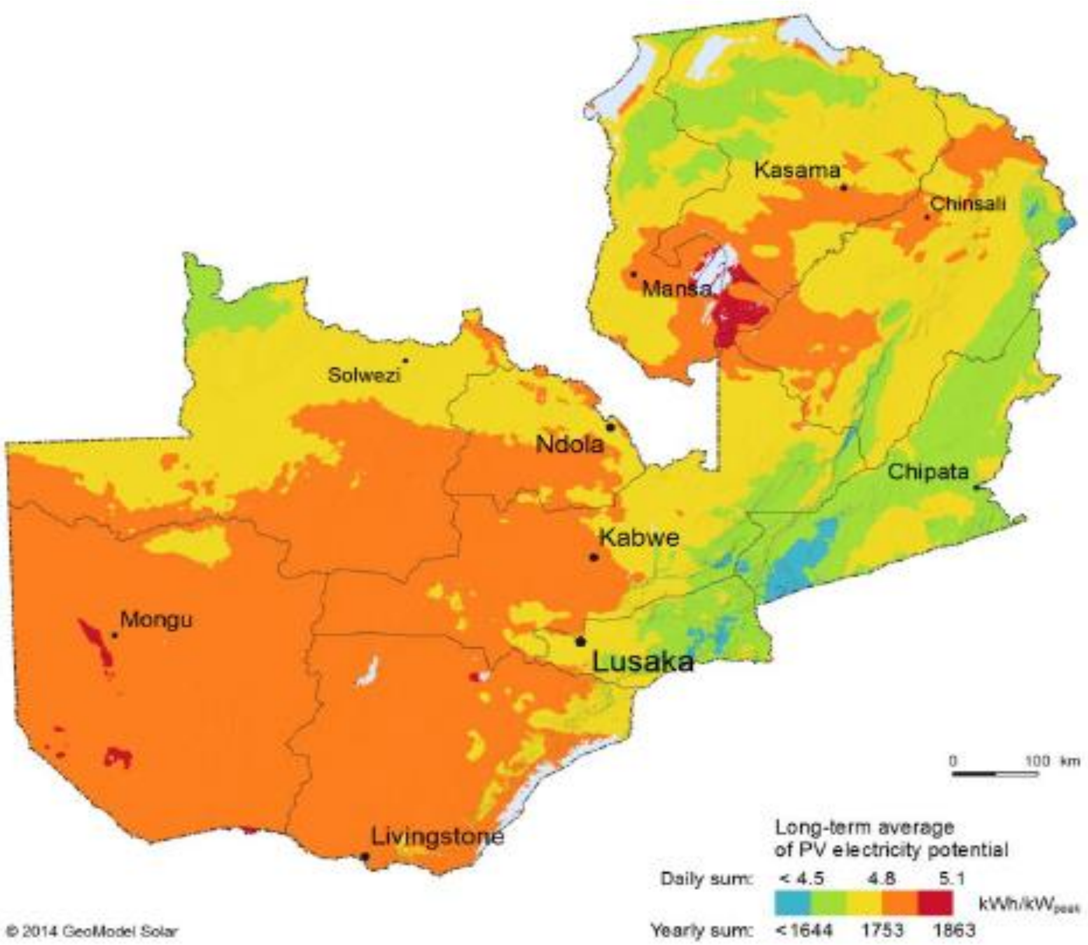
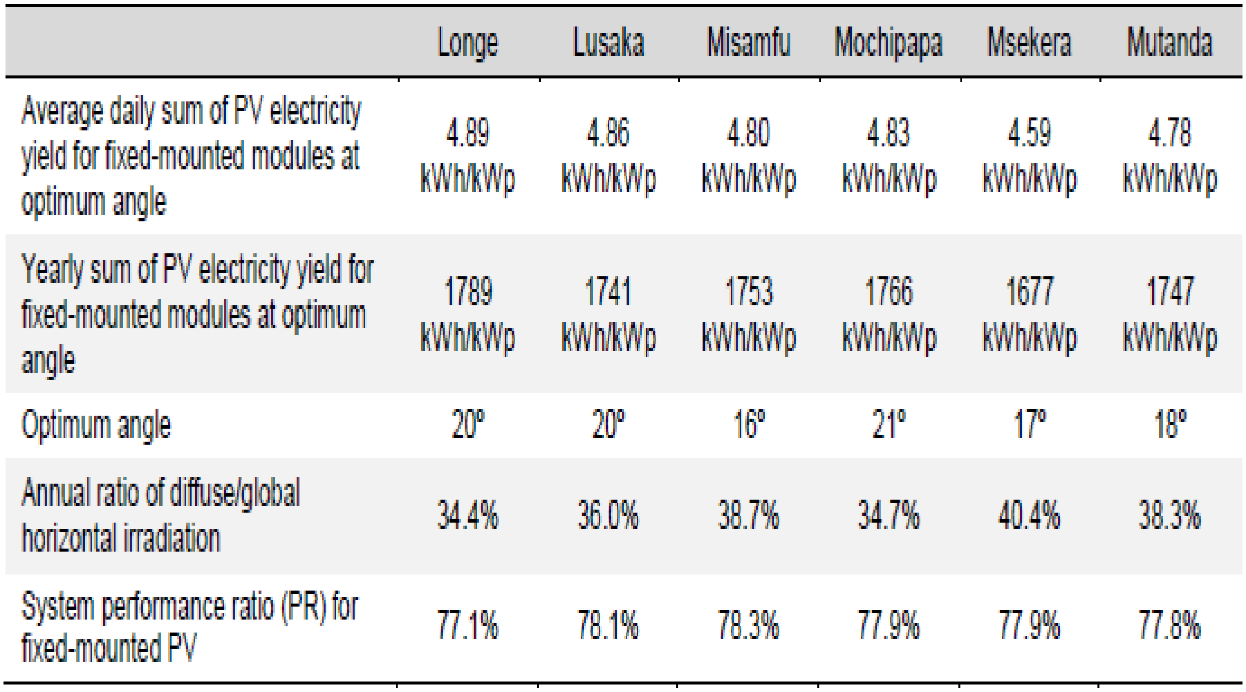


Figure 4*: Electricity output from a free mounted PV*

Source: modelling Report, World Bank (2014)

In Zambia, the average daily sum of specific PV power production from a reference system vary between 4.5kWh/kWp equivalent to yearly sum of 1640kWh/kWp and 5.1kW/kWp about 1860kWh/kWp yearly with extreme values in western province and southeast of Luapula province. This positions Zambia to regions with very high potential for PV generation (World Bank Group, 2014). There is not much inequality among regions in annual solar radiation, which is recorded relatively high and stable between 6.600 and 7,700MJ/m^2 /year which means Zambia has potential over the country. According to the data from the Zambia Meteorological department (ZDM), which is under the Ministry of Communication and Transport, the average annual solar radiation is 15.66MJ/m^2/day or 4.35kWh/m^2 /day in electricity conversion (Japan International Cooperation Agency, January 2008). Table 9 is the annual performance parameter of a PV system with modules fixed at optimum angle.

Table 9: Annual performance parameter of a PV system



	Longe	Lusaka	Misamfu	Mochipapa	Msekera	Mutanda
Average daily sum of PV electricity yield for fixed-mounted modules at optimum angle	4.89 kWh/kWp	4.86 kWh/kWp	4.80 kWh/kWp	4.83 kWh/kWp	4.59 kWh/kWp	4.78 kWh/kWp
Yearly sum of PV electricity yield for fixed-mounted modules at optimum angle	1789 kWh/kWp	1741 kWh/kWp	1753 kWh/kWp	1766 kWh/kWp	1677 kWh/kWp	1747 kWh/kWp
Optimum angle	20°	20°	16°	21°	17°	18°
Annual ratio of diffuse/global horizontal irradiation	34.4%	36.0%	38.7%	34.7%	40.4%	38.3%
System performance ratio (PR) for fixed-mounted PV	77.1%	78.1%	78.3%	77.9%	77.9%	77.8%

Source *modelling Report, World Bank (2014)*

The potential solar generation can be estimated by first assuming 1m^2 solar panel (approximately L=1.2m, B=0.8) is installed on one house. Therefore Potential Electricity Generation from solar power (kWh/year);

P(kWh/y)=Radiation(kWh/m^2/day)XArea(km2)X365(days/year)X106X efficiency………..2.2

2.9.5.3 Review of Issues from Solar Energy Resource

The solar modelling resource mapping carried by the World Bank group Zambia brings out how much abundant solar energy is available in the country. The report located six sites which recorded higher solar potential per $1m^2$. The total number of both rural and urban housing units, from the central statistical report of population and housing projection for 2035 and beyond could be used to determine the solar potential (Central Statistical Office, July 2013). Solar energy has in the recent past received a lot of attention both in terms of research and design and the good will from various local financing partners and international agencies. Therefore, this study assumed high penetration of this resource in the energy mix from the already identified projects for implementation.

2.9.6 Wind Energy Potential

The wind energy is one of the oldest natural resources that were exploited with mechanical systems. The extraction of wind power is an ancient endeavor, beginning with wind-powered ships and wind mills. The last century the wind power technology has been developed and wind turbines are being constructed in order to generate electrical power. The main driver for utilizing wind turbines to generate electricity is the low CO_2 emissions over the entire life cycle of manufacture, installation, operation and decommissioning and the potential of wind energy to help mitigate the climate change. The stimulus for the enlargement of this field was due to the oil crisis in 70’s and the concern over the fossil fuels scarcity (Renewable Energy Policy Network for the 21st Century (REN21), 2015).

The kinetic energy of the moving air particles can be converted to electricity or energy for pumping water using wind turbines. To understand how wind turbines function, it is useful to briefly consider some of the fundamental facts underlying their operation. The actual conversion process uses the basic aerodynamic force of lift to produce a net positive torque on a rotating shaft, resulting first in the production of mechanical power and then in its transformation to electricity in a generator. Wind turbines, unlike most other generators, can produce energy only in response to the resource (wind) that is directly available. It is not possible to store the wind and use it at a later time. The output of a wind turbine is thus inherently fluctuating and non-dispatch able. Any system to which a wind turbine is connected must take this variability into account. Another fact is that the wind cannot be transported: it can only be converted where it is blowing. Today, the possibility of conveying electrical energy via power lines compensates to some extent for wind's inability to be transported (Andrea, 2012).

Wind energy arises from the moving air particles across the Earth's surface. All winds are produced by differences in air pressure between two regions. These pressure differences are a result of the uneven heating of the Earth's surface from the sun. It is important to understand how much power is available in the wind in order to realize how much energy can be delivered from wind to energy systems. To examine this it is essential to briefly mention how wind is created. There are several atmospheric forces applied on an air particle to set it into motion and create wind. Such forces are the gravitational force, the pressure gradient force, the Coriolis force, friction, and centrifugal force

The gravitational force is directed downward perpendicular to the ground and is approximately equal to the mass times the gravitational acceleration ($g \approx 9.8 m/s$). The pressure gradient force always pushes from higher pressure towards lower pressure.

The energy available in a wind tube is kinetic energy, which is mathematically expressed as:

$KE = \frac{1}{2} mV^2$ ……………………………………2.3

Where m is the mass of the air particles passing through the wind tube and V the wind speed. The mass of the air particles can be obtained as:

$m = \rho .A.l$ …………………………………….2.4

Where ρ is the air density, A is the area of the wind tube; l is the length of the wind tube. The mass flow can be written as

$m = dm/dt = \rho.A.dl/dt = \rho.A.V$ …………………………2.5

The power available in the wind is

$P_w = dKE/dt = \frac{1}{2} .m.V^3$ ………………………………..2.6

Or by inserting the mass flow to the above equation the following formula for the power available in the wind is obtained

$P=/2.p.A.\ V^3$ ………………………………………………2.7

This formula is the basis of this analysis in order to obtain the theoretical wind power potential in the country. According to the metrological department there are about nine sites in Zambia were wind speeds have been measured at more than 5 meter/second as shown in the Table 10. Albert Betz, a German physicist showed that the fundamental laws of mass and energy conservation allow no more than 59.3percent of the kinetic energy of the wind to be extracted and converted to mechanical energy.

Table 10: Sites with Wind Energy potential

No	STATION	LONGITUDE	LATITUDE	WIND (m/s)	YEARS RECORDED
1	KABWE MET	28.48	-14.42	5.9	27
2	MONGU	23.17	-15.25	5.9	17
3	MKUSHI	23.17	-15.25	5.9	3
4	CHIPEPO	27.88	-16.8	5.2	2
5	LUSAKA HQ	28.32	-15.42	5	16
6	LUSITU	28.82	-16.18	5	6
7	KALABO	28.82	-16.18	5	11
8	KASAMA	31.13	-10.22	7.3	2
9	SAMFYA	29.32	-11.21	5.2	2

Source: Modified from ERB report and CSO reports (2015)

This is widely known as the Betz' limit. This means that no wind turbine can produce more than 59.3percent of the power available in the wind. Therefore due to the fact that air remains in motion after passing through the wind turbine. Betz's limit represents the maximum power coefficient that a theoretical wind turbine could reach.

2.9.7 Review of Issues from Wind Energy Resource

From the literature above the wind measured from the metrological department are on average considered as marginal speed in wind power technology. In Zambia wind energy is very much suitable for irrigation only. This energy could be drawn from the grid if the wind turbine are not installed for this purpose in identified sites.

In this investigation the sites with wind potential will be assigned arbitrary numerical values of the areas in meter square to enable quantification of this resource and add to the 2050 energy scenarios.

2.9.8 Bioenergy Potential

Bioenergy dominates the sub-Saharan energy mix, mainly account for the traditional use of solid biomass in the residential sector, while the modern use of solid biomass and biogas for power generation and heat make up only a very small share. Forest products and residues, and agricultural residues represent a significant portion of the available biomass resources, though some residues represent a significant portion of the available biomass resource, though some residues must be left in-field to maintain the agriculture productivity of the land (Africa Enegry Outlook , 2014)

2.9.8.1 Biomass-Agriculture

The bulk of energy from biomass fuel in developing countries is consumed by households mostly for cooking purposes and Zambia is not an exception. Biomass constitutes a major source of the energy use in Zambia especially in the household sector where more than 80 percent of the cooking needs come from biomass (Kaoma, Mwanza, & Mpanga, 2017).

Agriculture is an important part of the economy in most of the developing countries including Zambia. Of the 752,000 square kilometres total land area of Zambia, about 43 million hectares (58percent) is classified as medium to high potential for agricultural production. Only 14percent of the agricultural land is currently utilized. Besides the crop itself, large quantities of residues are generated every year from agriculture activities. The term agricultural residue is used to describe all the organic materials which are produced as by-products from agriculture activities. These residues constitute a major part of the total annual production of biomass residues and are an important source of bioenergy. For assessing agriculture economic biomass resource potential. The following equation can used;

$$HR = P \times h \times hr \qquad \text{2.8}$$

Where HR-Energy resource from crop residues (tons/year)

P- Production of crops (tons/year)

h- Harvest residue ratio, defined as the ratio between the amount of residues generated and

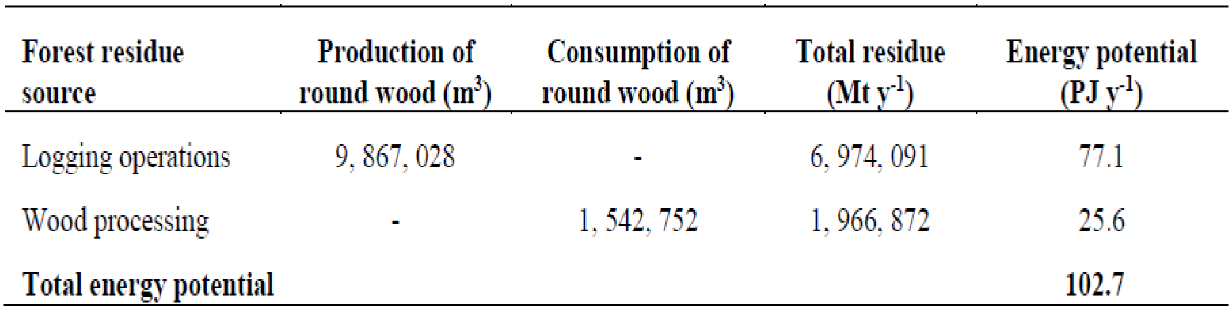
The amount of residues generated and the amount of crops produced (dimension)

The biomass potential for 2012/13 farming season was estimated as 1.352GWh (Kaoma, Mwanza, & Mpanga, 2017).

2.8.8.2 Biomass -Forest

Forest residues are generated from the forest product industry can be divided into two categories: (1) logging residues, generated from logging operations, for example, from final felling and (2) industrial by products, generated by the forest industries during processing of timber, plywood, particleboard, and so on. Sawdust is one example of industrial by products generated from about 400 sawmills in Zambia. Woodlands and forest which are sources of forest residues are estimated to cover about 50 million hectares (66percent) of Zambia's total land area (Kaoma, Mwanza, & Mpanga, 2017). Given the low income level of energy consumers and the abundance of wood resource, it is foreseen that firewood and charcoal will continue to dominate Zambia's energy consumption. The estimated energy potential for the forest residue is as shown in Table 11.

Table 1: Bioenergy production potential from forest residues



Forest residue source	Production of round wood (m^3)	Consumption of round wood (m^3)	Total residue ($Mt\ y^{-1}$)	Energy potential ($PJ\ y^{-1}$)
Logging operations	9, 867, 028	-	6, 974, 091	77.1
Wood processing	-	1, 542, 752	1, 966, 872	25.6
Total energy potential				**102.7**

Source: M.Kaoma et al (2017)

2.9.8.3 Biogas -Municipal Solid Waste

Municipal solid waste (MSW) is defined as solid waste which include all domestic refuse and non-hazardous waste such as commercial and institutional waste, street sweepings and construction debris. Generation of MSW in Zambia is on the increase due to rapid rise in population, changing life style and popularity of fast foods and disposable utensils (Kaoma, Mwanza, & Mpanga, 2017). The potential energy that can be generated through anaerobic digestion (biogas production) technology was assessed. According to Environmental Council of Zambia, the average MSW generation rate in Zambia is 0.5 kg/capita/day. The potential energy generation in MSW can be determined using equation…

$$E_{msw} = \eta_{of}.\ MSW_q.\ B_y.\ \eta_{vs} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.8$$

Where; η_{of} is the organic fraction of the MSW generated in Zambia (which is 0.5 in this case)

MSW_q is the quantity of the municipal solid waste generated annually in Mt/y,

B_y is the ultimate biogas yield (kJ/kg VS),

η_{vs} is the ratio of volatile solid dry matter.

The total actual electricity/energy from bioenergy was estimated at 327.26 MW, coming from agriculture 299.92MW, waste (5.0 MW), municipal solid and liquid waste (20.78MW), and animal waste (81.56MW). This potential represents 13.6percent of the total energy demand of approximately 2400MW (CEEEEZ Company, 2016).

2.9.8.4 Review of Issues from Bioenergy Resource

From the literature on bioenergy potential, the data Figures used was narrow as it only considered biomass from small scale agricultural production output for that season. Therefore the energy potential from this work is representative of the biomass agricultural energy potential for small area of Zambia. Further, biogas potential was calculated for only 12 towns/ cities (Kaoma, Mwanza, & Mpanga, 2017) . The biogas potential from municipal solid waste is quiet extensive work since a represented potential from this resource can only be effectively estimated for the base year and aggregated to the year of focus. Therefore in this study biomass potential will only consider the power generation from existing plants such biomass combustion from Nkambala and Kafue sugar respectively. The two plants have a combined capacity of about 48MW which will be included in the simulation (CEEEEZ Company, 2016).

2.9.9 Geothermal energy

The Earth’s heat is a combination of radioactive decay of uranium, thorium, and potassium in the Crust and Mantle, and primordial heat left over from the planet’s formation. Geothermal energy is derived from the heat contained in the Earth, which is recognised as essentially limitless, its use being only restricted by technology and the associated costs. It is environmentally clean, renewable and is the largest energy source available to mankind. Geothermal energy can be used directly as a heat source with a range of industrial applications, or indirectly in a thermal power plant to produce electricity .The amount of heat that flows annually from the earth to the atmosphere is enormous – more than needed to power all nations of the world if it could be harnessed. If only 1percent of the thermal energy contained in the uppermost 10km of our planet could be tapped this amount would be 500 times that contained in all oil and gas resources of the world. Geothermal targets must be sufficiently hot (>130^{o}C) and sufficiently close to surface (<4 km) to justify commercial development. Exploitable targets have been associated with areas of recent volcanic activity – Pacific Rim (including western seaboard of America), Italian Alps, Iceland and the East African Rift System, which are largely high enthalpy. However, there are a larger number of low enthalpy geothermal systems that also have the potential to produce power and it is these that may provide the energy for the majority of globally produced geothermal power in the future (Kalahari GeoEnergy Ltd, February 2013).

In Zambia, the geological Survey of 1974 reconnaissance of Hot & Mineralised Springs about 86 springs were identified alongside some basic hydro-chemistry.The Zambian-Italian Government joint Geothermal Project around mid-1980's carried out the following tasks (Kalahari GeoEnergy Ltd, February 2013);

- Hydrochemistry, geophysics and shallow drilling (<150m) at 4 sites
- 220kW Turbo binary geothermal pilot plant installation at Sumbu, Lake Tanganyika
- Sumbu plant is held by ZESCO but no subsequent development work was undertaken.

In 2006, KenGen (Kenya) consultancy to Zambia Government carried further review of the Geothermal potential in the country. In their report, economic potential (> 2MW) of Sumbu and Chinyunyu was highlighted as one of the two geothermal targets investigated. Kalahari exploration follow up suggests that Chinyunyu has limited potential and that further geophysical exploration and drilling is required at Sumbu (Kalahari GeoEnergy Ltd, February 2013).

Currently the most prospective geothermal setting are Karoo Sedimentary Basins within Rift Structures, characterised by high porosity rocks; includes those targets with highest geothermometer temperatures calculated as greater than160^{O}C and significant fluid / rock ratios. The sedimentary basin geothermal model concept is of fluids circulating in deep faults within the crystalline rock basement complex below clay rich sediments (the Karoo sedimentary basin) heated by geothermal gradient and trapped below the clays. The objective is to locate and mine the heat from appropriate aquifers, which for indicative geothermometers of $160^{O}C$ should not be too deep perhaps 2,000m (Kalahari GeoEnergy Ltd, February 2013).

Based on current exploration results, the Company's assessment is that "the Lochinvar target has the characteristics of a realistic geothermal power target, which if proven to be a shallow, permeable, tabular reservoir could be relatively low cost to target and develop, using binary plant technology.

2.9.9.1 Review of Issues from Geothermal Energy

Very little literature is available on the geothermal energy potential in Zambia and the available Literature does not show promising evidence of huge potential for geothermal energy potential in Zambia. Therefore in this study geothermal energy addition to the 2050 energy mix will be allocated share equivalent to site potentials.

2.10 Energy Modeling Software options

In this study three options of the available software for energy modeling were evaluated. The modeling software evaluated were MARKAL, Energy Plan, and LEAP software.

2.10.1 MARKAL Modeling Software

MARKAL is a large scale linear programming optimization software model, first developed in the 1970s at Brookhaven National Laboratory to support strategic energy planning. It is widely used in the international community to support integrated analysis of environmental options, such as reduction of greenhouse gas emissions, and to explore mid to long term responses to different technological futures, emissions limitations, and policy scenarios (Richard, Gary, & Ken, 2004).

In MARKAL, an energy system is represented as a set of energy technologies that extract, transport, convert and use energy. MARKAL captures the complex interrelationships of energy system from the primary energy supply to energy services demands and optimizes the given energy system by minimizing cumulative system cost over the time period (Coelho, 2001).

In standard MARKAL several options are available to model specific characteristics of an energy system such as the internalization of certain external costs, endogenous technological learning and the representation of certainty in some model parameter. MARKAL is an expensive software and the price for the software is dependent on the intended use, the number of people using the software and the organization purchasing the software, as such it is not a free ware.

2.10.2 EnergyPlan Modeling Software

EnergyPlan is primarily a simulation model, but it also includes some optimization. In Energy plan the user designs an energy system in terms of demands, capacities, efficiencies, and costs and once it is complete the user simulates how that energy system performs. During simulation the model can be instructed how to optimize each day of the year hour by hour of the simulation (Energy PLAN, 2015).

The most common optimization used in EnergyPlan is technical optimizations where as the main objective is to reduce energy consumed during the simulation. It is important to note that the optimization only refers to the operation of the energy system during each hour and not to the design of the energy system (SETIS , 2016).EnergyPlan is a free ware available on open source with technical services support.

2.10.3 LEAP Modeling Software

LEAP was originally created in 1980 for the Beijer Institute's Kenya Fuel Wood Project, to provide a flexible tool for long-range integrated energy planning. LEAP provided a platform for structuring data, creating energy balances, projecting demand and supply scenarios, and evaluating alternative policies, the same basic goals as the current version of LEAP. LEAP was originally implemented on a mainframe computer. In 1983, with funding from US-AID, it was converted for use on a minicomputer and a first user-interface was added with the aim of transferring it to energy planners in Kenya and elsewhere. By 1985, LEAP had been ported again, this time to the newly Review of IBM PC microcomputer, making wider dissemination and a more user-friendly interface possible. In the course of the 1980s, LEAP-based studies were conducted in a dozen countries in Africa, Latin America, and Asia (SEI, 2013).

In the 1990s, with concern about the environmental impact of energy systems growing, LEAP became one of the first energy modeling tools to address this concern through the addition of the Environmental Database (EDB) and enhancements for computing emissions loadings in LEAP (SEI, 2013).

The Long-range Energy Alternatives Planning system (LEAP) is a widely-used software tool for energy system, policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute (SEI).

LEAP is not a model of a particular energy system, but rather a tool that can be used to create models of different energy systems, where each requires its own unique data structures. LEAP supports a wide range of different modeling methodologies: on the demand side these range from bottom-up, end-use accounting techniques to top-down macroeconomic modeling. On the supply side, LEAP provides a range of accounting and simulation methodologies that are powerful enough for modeling electric sector generation and capacity expansion planning, but which are also sufficiently flexible and transparent to allow LEAP to easily incorporate data and results from other more specialized models (SEI, 2013). Leap is a free ware available on open source with the associated support.

2.10.3 Critic of the Modeling Software

There are several other energy modeling software available on the market today. This study has only looked at three energy modeling software to avoiding diverting from the objectives of this research. In the evaluation of the modeling software to be applied to help unlock the research questions, three main parameters i.e. characteristic features, long time horizon, software support service and cost were analyzed for each of the above modeling software above.

MARKAL Energy Modeling software has the requisite characteristic features capable of integrating the supply and demand as well as optimization aspects. Since this software is not free, support services is readily available at a cost. Additionally its applicable time horizon is medium to long term, suitable for the 2050 energy mix scenarios under investigation. However the cost of MARKAL was beyond the funds available for this research and as such this software could be adopted for this study.

EnergyPlan Modeling software is good for simulating hourly energy system in a period of one year. It is not suitable for long time horizon. Despite EnergyPlan being a free ware with support service, it does not help answer the research questions in this inquiry.

LEAP Tool has all the required characteristic features, long time horizon for analysis, software support with an open discussion forum and it is a free software. The software is responsive to the aim and objective and it was adequate to use in this study. Its most important features for this study are its alternative scenario analysis, calculation of different energy technology from various primary energy and the ability to combine bottom up energy demand forecast and modeling of energy supply.

2.11 Highlights from literature Review

In this Chapter the amount of hydropower potentials which are yet to be exploited were looked at for addition to the power system. The literature offered a great deal of solar energy which could be added to the primary energy mix in 2050.Apart from the estimation of solar using total number of houses in Zambia, solar farm could still form medium to large power plants in 2050.The wind measurement are on average considered as marginal speeds in wind power technology for the Zambian case. Therefore wind energy contribution to the 2050 energy mix will be a small portion is used in irrigation which otherwise could be drawn from the power system. Bioenergy either from agricultural biomass or biogas from municipal waste has a lot of potential to significantly contribute to the 2050 primary energy. There is little literature on geothermal energy though exploitation of this primary is still going with some estimated potential and as such its contribution will be taken into account. The confirmed reserves of coal is sufficient to contribute to the energy mix until 2050, though the amount of reserves will have depleted to almost half the current estimates. The next chapter covers the methodology used in this study.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes methods used for data collection from secondary sources about the primary energy resources for electricity generation in Zambia available within its boundaries. Drivers of electricity demand will also be presented. The chapter concludes with the scenario analysis approach to energy mix for the year 2050. Quantitative research methods was used for data from published text books, technical reports, government documents, journals, articles and conference proceedings. The data collected is mainly presented in form of tables and where possible mathematical equations were used to explain the data.

3.2 Research Design

The research was designed to develop the final energy carrier (electricity) demand and primary energy supply for the base year 2015.Then project electricity demand and primary energy supply based on the set of assumptions and key drivers for the year 2050.The main input on demand were population, household size, number of housing, gross domestic product (GDP), end year urbanization and industrial energy consumption patterns. The main source of data for inputs were Central Statistics Office, Energy Regulation, ZESCO limited and supplemented by other publication. The input on primary energy supply were published existing power plants and future power plant driven by various primary energy options within Zambia. The main source of data for power plants were ZESCO limited, Energy regulation board, Power system studies on future plants by JICA, REA and world bank funded studies on renewable energy. The tool used to model the 2050 energy mix was a computer software called Long-range Energy Alternative Planning (LEAP). LEAP is an integrated modeling tool that can be used to track energy consumption, generation and primary resource extraction in all sectors of an economy.

All the data for both the demand drivers and primary energy supply options were collected and manually entered in Leap Software for base year 2015 in order calibrate the leap model. Then three scenarios were constructed using different set of assumption and simulated the final energy (electricity) demand and primary supply options to output energy mix for 2050.

3.3 Energy Demand

Generally the energy demand sectors are divided into two types, industrial and residential or households sectors. The industrial or economic category consist of Mining, Quarry, Manufacturing, Energy and Water, Trade, Transport, Finance and Property and others.

3.3.1 Household Sector

Household sector is mainly driven by population size, urbanization, number of housing units, and access to electricity by urban and rural areas and to greater extent income growth rate. The energy demand from residential sector, in this study was determined by considering energy intensity for various activity in the household such as Lighting, Cooking, Heating, Refrigeration and other uses. From the outset the housing units in Zambia consist of two categories, rural and urban subsector. In each subsector, there are electrified and non-electrified housing units. Figure 5 shows the household sector tree. The tree breaks down the energy consumption flow by rural and urban housing numbers. It further separates electrified and non-electrified until the equipment energy consumption per house.

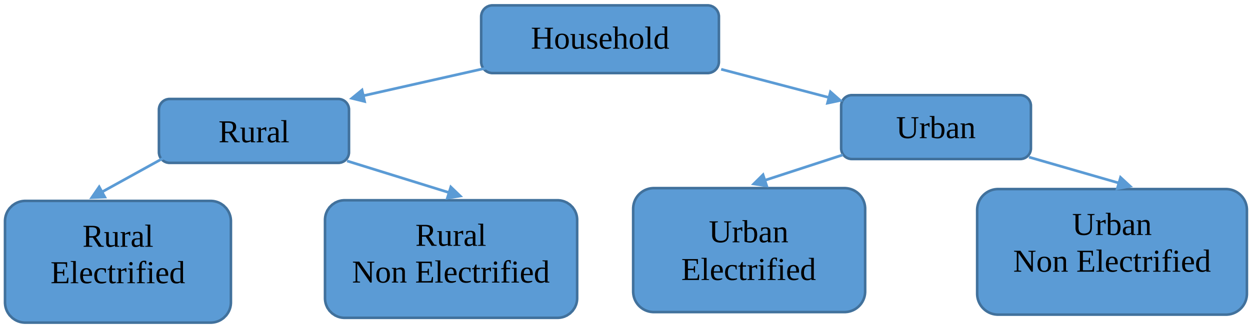


Figure 5*: Categorization of Household*

At the housing unit level, demand is driven by various activities that support human needs and wants. For each of the activity, final energy intensity consumption was calculated per year in the household sector. The equipment rating such as electric stoves, refrigerator, geyser, and iron were used to estimate the consumption using the formula below.

Energy Intensity per activity (kWh) = Rating (kW) X hours operated in a year (hrs.)…….3.1

The calculation of electricity consumption of various equipment in an urban subsector is shown in Figure 6.

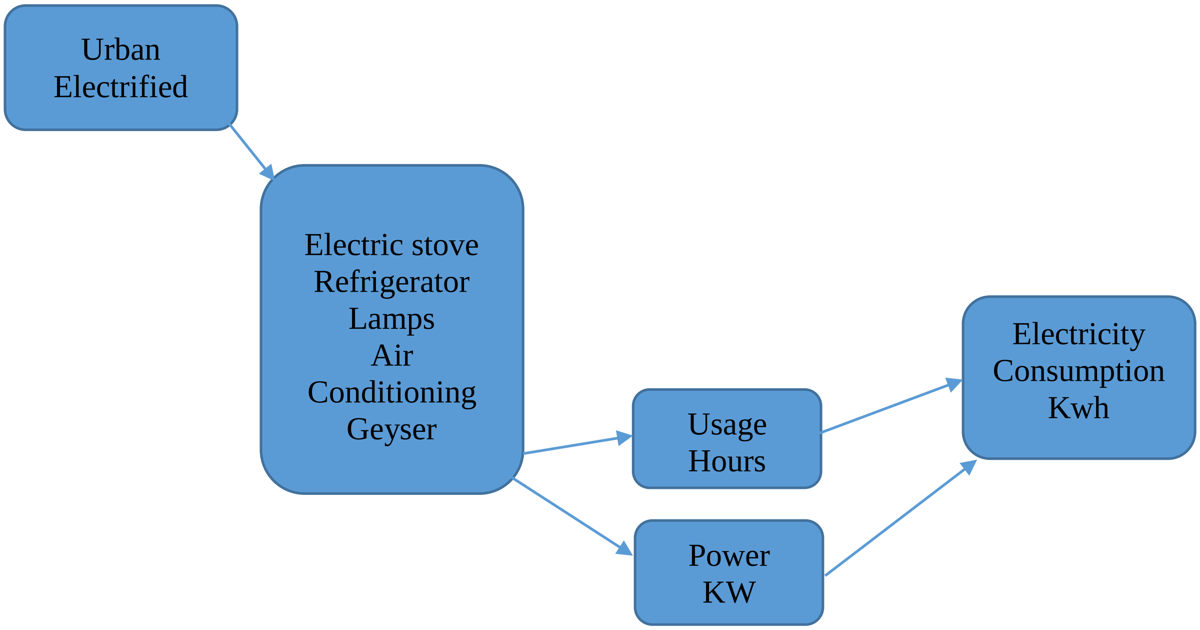
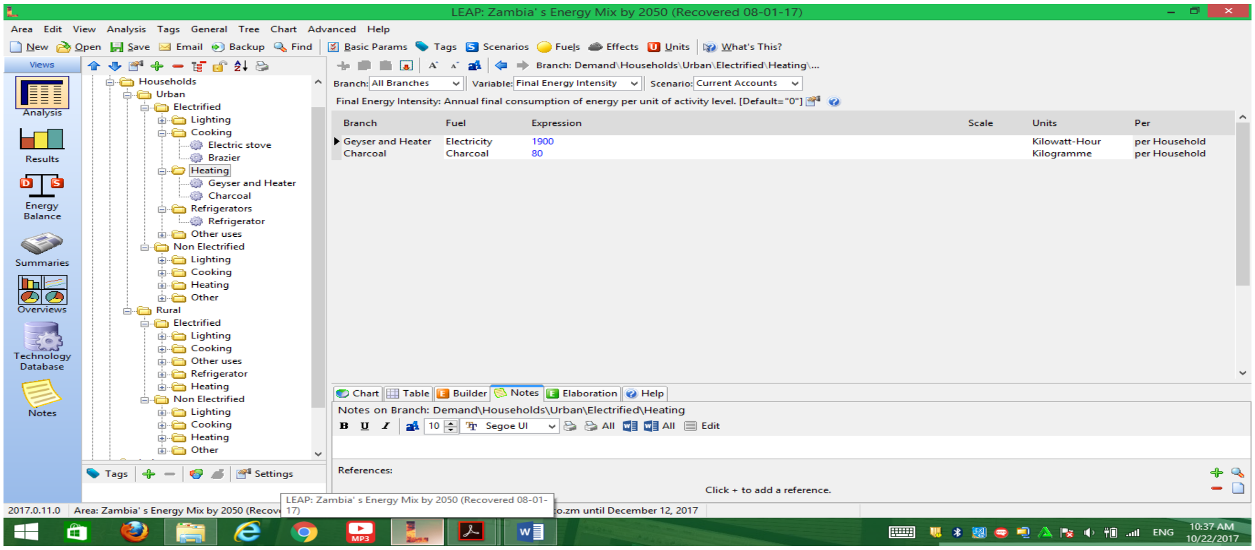


Figure 6: ***Calculation of Electricity Consumption of Equipment***

The calculated energy intensity was for various household activity were then input in the base year (current account) for 2015 in LEAP model as shown in Figure 7 which forms the basis for projection of the 2050 energy demand.



LEAP: Zambia' s Energy Mix by 2050 (Recovered 08-01-17)

Branch: Demand\Households\Urban\Electrified\Heating\...

Branch: All Branches Variable: Final Energy Intensity Scenario: Current Accounts

Final Energy Intensity: Annual final consumption of energy per unit of activity level. [Default="0"]

Branch	Fuel	Expression	Scale	Units	Per
Geyser and Heater	Electricity	1900		Kilowatt-Hour	per Household
Charcoal	Charcoal	80		Kilogramme	per Household

Notes on Branch: Demand\Households\Urban\Electrified\Heating

References:

Click + to add a reference.

2017.0.11.0 Area: Zambia' s Energy Mix by 2050 (Recov

LEAP: Zambia' s Energy Mix by 2050 (Recovered 08-01-17)

o.zm until December 12, 2017

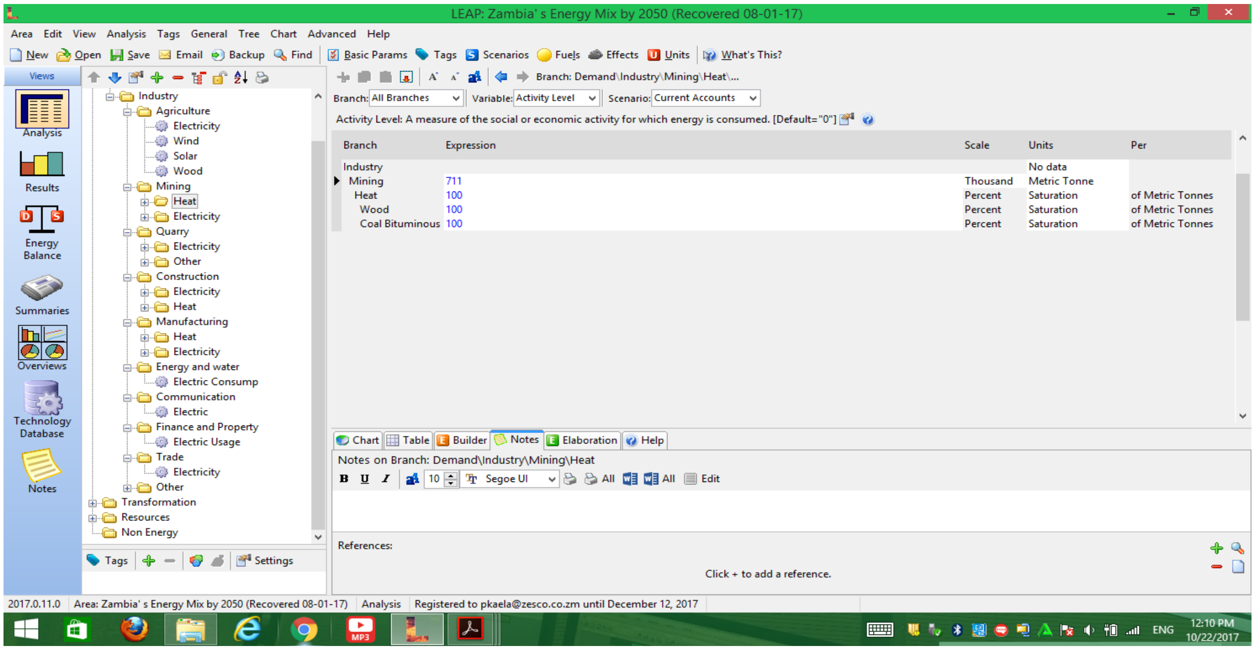
Figure 7: ***Household Activity and final Energy Intensity demand data SEI (2018***

Source: Stockholm Environmental Institute (2018)

Cooking activity using charcoal was calculated from data obtained from the Zambia's Energy Statistics Report (Central Statistical Office, October, 2015).The reported total charcoal consumption by both urban and rural households was divided by the number of housing to get the consumption per year for a unit and then the Figures were input in the LEAP model.

3.3.2 Industrial Sector.

The structure of the economic development has a determining role in the future energy demand. The main driver of estimating demand in this sector is based on the gross domestic product (GDP). However, energy demand does not only depend on the growth of GDP but the changes in the structure of GDP, i.e. the growth of different economic sector and changes in their technology. This is because different economic sectors have considerably different energy intensities. The demand for the base year 2015 was obtained for all the subsectors in the economic sector. The mining subsector is one of the major consumer of the energy in Zambia (Energy Regulation Board, 2015). Therefore, the energy consumption for base year 2015 and energy projection for subsequent year for mining was based on the production quantities of all minerals in mining subsector. For all subsectors in the economic sector base year calculation were based on the GDP to simplify the modeling of the demand for industrial sector as shown in Figure 8.



Branch: Demand\Industry\Mining\Heat\...

Branch: All Branches Variable: Activity Level Scenario: Current Accounts

Activity Level: A measure of the social or economic activity for which energy is consumed. [Default="0"]

Branch	Expression	Scale	Units	Per
Industry			No data	
Mining	711	Thousand	Metric Tonne	
Heat	100	Percent	Saturation	of Metric Tonnes
Wood	100	Percent	Saturation	of Metric Tonnes
Coal Bituminous	100	Percent	Saturation	of Metric Tonnes

Notes on Branch: Demand\Industry\Mining\Heat

2017.0.11.0 Area: Zambia' s Energy Mix by 2050 (Recovered 08-01-17) Analysis Registered to pkaela@zesco.co.zm until December 12, 2017

Figure 8: *Industrial Sector Activity Tree*

Source: Stockholm Environment Institute (2018)

3.4 Energy Supply

On the supply side, data used in the LEAP model was given generation data of all existing generation plant capacities and associated historical energy production. Further, all planned generation expansion project with estimated capacities were also feed in the model. Depending on the demand in any particular year the model is programmed to determine which of the planned generation plants should be commissioned to meet the demand. For power plant with specific life span such as thermal and solar, the model is also programmed to retire such plant after the expiry of its life span.

3.5 Primary Energy data Collection.

From the primary energy supply option in the literature review, about seven sources of primary energy within Zambia's borders were identified as shown Figure 9.

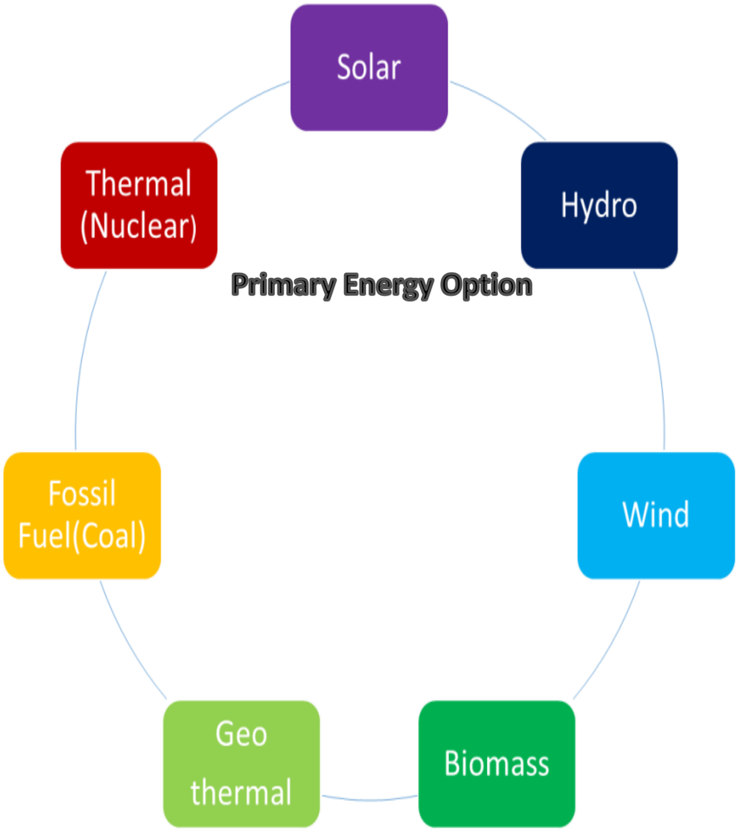


Figure 9: ***Primary Energy Supply Option***

In this study primary energy data with reported or confirmed capacities were collected and used as the input to the study. Primary energy such as Nuclear and Biomass were not used because there is no reported capacities yet for these primary resource although it is available. Tables 12 presents various primary energy reported capacities in Zambia used for in this investigation.

Table 22: Total Capacity of Existing Power Plants

S/N	NAME OF POWER PLANT	CAPACITY MW	RIVER	COMMENTS
1	KAFUE GORGE-PS	990	KAFUE	EXISTING
2	KARIBA NORTH-PS	1080	ZAMBEZI	EXISTING
3	VICTORIA FALLS-PS	108	ZAMBEZI	EXISTING
4	LUNZUA	14.8	LUNZUA	EXISITING
5	LUSIWASI	12	LUSIWASI	EXSITING
6	CHISHIMBA	6	CHISHIMBA	EXISTING
7	MUSONDA	5	LUOMBE	EXISTING
8	SHIWANG’NDU	1		EXISTING
9	LUNSEMFWA	31	LUNSEMFWA	EXISTING
10	MULUNGUSHI	25	MULUNGUSHI	EXISTING
11	ITEZHI-TEZHI	120	KAFUE	EXISTING
	CURRENT TOTAL	2392.8		

3.5.1 Hydropower

Table 12 list the total capacities of the existing hydropower plants which were used to calibrate the model on the primary energy supply for the base 2015. This data was entered on the leap generation module for the purpose of calculating the quantity of the required primary energy for electricity generation in the base. Table 13 shows the total capacities of future hydropower plants which are expected to be added to the power system as the demand increases. This data was entered on the leap generation module for the purpose of calculating the quantity of the required primary energy for electricity generation until the target year 2050.

Table 33: Future hydro Plant Capacities

No.	NAME OF SITE	TOTAL (MW) CAPACITY	RIVER	COMMENTS
1	KABOMPO GORGE	40	KABOMPO	Under Construction
2	KABWELUME FALLS	96	KALUNGWISHI	IA signed
3	KUNDABWIKA FALLS	151	KALUNGWISHI	IA signed
4	CHAVUMA FALLS	14	ZAMBEZI	Feasibility/IA negotiations
5	CHANDA FALLS	1	KASHIJI	Developer Procurement
6	NGONYE FALLS	40	ZAMBEZI	Feasibility
7	MUCHINGA	230	LUNSEMFWA	Feasibility
8	LUCHENENE	34	LUCHENENE	Pre-feasibility
9	MUTINONDO	43	MUTINONDO	Pre-feasibility
10	MULEMBO/LELYA	330	MULEMBO	Prefeasibility
11	MAMBILIMA FALLS I	126	LUAPULA	IGMOU/Feasibility
12	MAMBILIMA FALLS II	202	LUAPULA	IGMOU/Feasibility
13	MAMBILIMA FALLS V	372	LUAPULA	IGMOU/Feasibility
14	MUMBOTUTA FALLS	490	LUAPULA	IGMOU/Feasibility
15	BATOKA GORGE	800	ZAMBEZI	Feasibility
16	DEVIL'S GORGE	800	ZAMBEZI	Pre-feasibility
17	MPATA GORGE	600	ZAMBEZI	Pre-feasibility
18	KAFUE GORGE LOWER	750	KAFUE	Under Construction
	POTENTIAL TOTAL	**5119**		

3.5.2 Solar Energy

Solar energy potential is expected be at 25 percent of the installed generation capacity. Table 14 shows some the confirmed solar projects with their expected commissioning dates. The capacities were entered in the leap software generation module to quantify the required primary energy from solar. However, solar energy addition was only limited by 25 percent of the installed capacity.

Table 44: Future Plant Capacities

No.	Project Name	Total Capacity (MW)	Proposed Site	Comment
1.	Solar Phase 1	76	Lusaka	Expected in 2018
2	Solar Phase 2	174	N/A	Expected in 2019
3	GETFiT Project	50	N/A	Expected in 2019

3.5.3 Thermal Plants

The existing thermal plants capacities were entered in the 2015 base year energy requirements while future confirmed thermal were added to the energy requirement depending on the demand in the leap model. Table 15 shows capacities of both the existing and future plants.

Table 55: Existing & Future Thermal Plants

No.	Plant /Project Name	Total Capacity (MW)	Location	Comments
1.	Maamba Coal	300	Sinazongwe	Commissioned in 2017
2.	EMCO Project	400	Sinazongwe	
3	Zambia Sugar	40.5	Mazabuka	
4	Kafue Sugar	8.0	Kafue	

3.5.4 Geothermal

Geothermal energy potential in Zambia is still being investigated. In this study geothermal addition to the primary energy required was limited to the existing and future plants shown in Table 16.

Table 66: Existing & Future Geothermal Plants

No.	Plant /Project Name	Total Capacity (MW)	Location	Comments
1.	Kapisya Hot Spring	2.2	Shiwang'ndu	Commissioned in 2017
2	Lochnvar Project	20	Monze	Expected by 2022

3.5.5 Wind

No specific capacities and site has been reported on the utilization of wind power in Zambia. However, there are sites which have marginal parameter suitable for installation of wind turbines.

Therefore the study included a small amount of wind power installed at big farms for irrigation and provision of water for animals which otherwise would directly use Electrical energy from other primary energy.

3.5.6 Biomass

In this study biomass energy generated from the sugar process industry has been included. Zambia Sugar and Kafue Sugar who operate at 40.5MW and 8.0MW respectively have been included in the study because excess generation from these plants could be feed into and drawn from the grid.

3.6 Demand Data Collection

In this study secondary data for demand and its drivers was collected from various reports, journal and other publication. There are basically two categories of energy demand sector in Zambia, Industry (economic) and Household residential (Spalding-Fecher, 2016).Both industry and household are driven by the key econometric driver shown in Figure 10.The main driver for industry energy demand is the gross domestic product growth rates while there rest of other drivers contribute household sector energy demand. These key drivers were used to model demand from base 2015 to target year 2050.

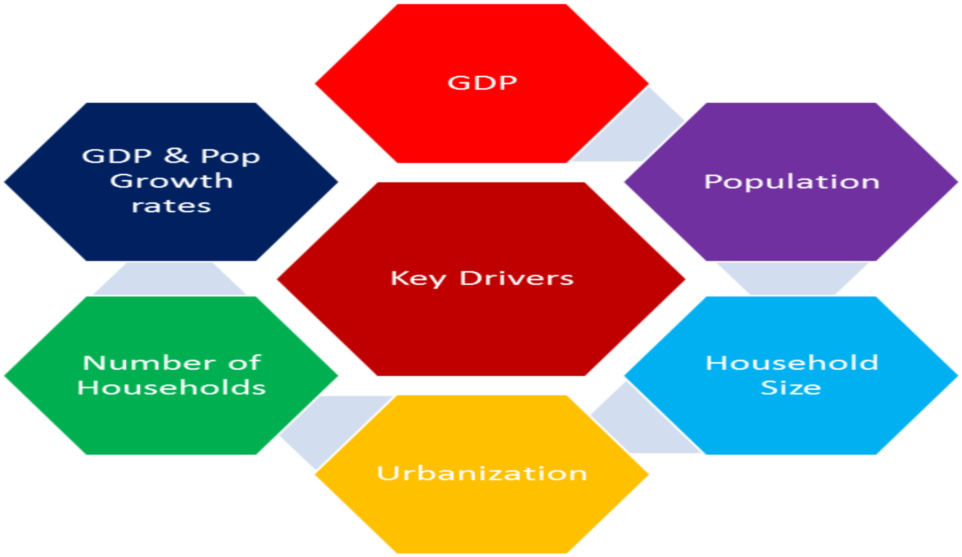


Figure 10: ***Key Demand Divers*****.**

3.6.1 Services (Household) Energy Demand Sector

The Services or residential energy demand sector basically consists of household units in the country which are divided into urban and rural. The main key drivers of this sector are population and household size, number of households, urbanization trends and access to electricity (Spalding-Fecher, 2016). The base year 2015 key demand drivers used in this study are as shown in Table 17.This data was used calibrate the base year household energy demand sector in leap modeling tool.

Table 17: Base year Key Drivers

No.	Key Driver	Base Year 2015
1	Gross Domestic Product	$21.5 Billion
2	Population	15.5 Million
3	Household Size	5.2
4	Number of Household	3.0 Million
5	Urbanization	40.5 percent

3.5.2 Industrial Energy Demand Sector

There are basically two categories of energy demand sector in Zambia, Industry and Household residential. Industry or economic sectors consist of Mining, Agriculture, Quarry, Construction, Manufacturing, Trade, Energy and Water, Finance and property, and other sectors. Mining in the industrial sector is the major consumer of the final energy utilization intensity at slightly above 50percent. The main key driver of the industrial energy demand sector is the national gross domestic product to which each industry contributes.

Table 18 tabulates the final energy electricity by sector for a five year period. The demand for the year 2015 was used for leap software calibration for industry energy demand sector.

Table 18: Electricity Energy Demand (MWh) for 2010-2015

SECTORS	YEAR 2011	YEAR 2012	YEAR 2013	YEAR 2014	YEAR 2015
OTHERS	299,004	140,732	126,035	108,056	98,494
AGRICULTURE	193,692	226,890	238,310	265,338	260,426
QUARRY	14,110	54,393	18,610	6,944	68,188
MANUFACTURING	403,787	556,273	487,682	549,188	530,772
ENERGY AND WATER	88,694	81,201	78,840	80,339	89,069
CONSTRUCTION	9,803	10,016	13,395	18,807	15,198
TRADE	144,109	143,564	133,020	117,985	109,809
TRANSPORT	21,830	22,689	24,395	34,117	33,363
FINANCE AND PROPERTY	345,862	397,167	454,531	533,514	516,927
SERVICES(HOUSEHOLDS)	2,782,896	3,021,772	3,223,394	3,567,259	3,482,025
MINING	5,050,211	5,050,211	5,751,821	5,905,003	6,220,619
TOTAL	**9,353,998**	**9,704,908**	**10,550,033**	**11,186,550**	**11,424,890**

Source ERB report (2016)

3.7 Modeling Simulation Approach

There are generally three main modeling approaches; bottom up, top down, hybrid and input-output energy models.

3.7.1 Bottom up Models

In the modeling of the energy sub-system, bottom-up energy models, or partial equilibrium models, can be divided into supply-side and demand-side models. In bottom-up modelling, energy demand is treated as given, which helps in the optimization of the energy system. Bottom-up energy models typically include larger shares of renewable energy and low-fossil technologies. In energy modeling this makes these technologies increasingly competitive over a long-term period (Andrea, 2012). Bottom-up models in turn, often have been constructed and used by engineers, natural scientists and energy companies. Bottom-up approaches can provide an elaboration of needs at a localized level (household, community or region) and more detailed analysis from and engineering perspective.

3.7.2 Top down Models

Top-down energy models include computational general equilibrium models, economic models, input-output models, and system dynamics models that treat the energy system as a part of the macro-economy (Andrea, 2012), (Thomas & Unger , 2010). Top-down models aim for the optimization, or an economic equilibrium, between supply and demand for energy. Computational general equilibrium models have been employed to analyze policy implications for economies, and have become a standard tool in many countries and international research organizations (Honkatukia, 2013). Top-down energy models present costs for technology change higher than bottom-up energy models, and following their logic makes acting on climate change seem more difficult

Because top-down models are ineffective in assessing technological evolution to achieve a low-carbon economy (Proença & Aubyn, 2009) this raises profound points of consideration with regard to climate change action. In the past, energy scenarios have mainly been constructed for the state and the energy intensive industries.

3.7.3 Hybrid Models

Hybrid energy models mix the bottom-up and the top-down approaches and could improve understanding about and attempt to overcome limitations of both approaches. Hybrid models have emerged only recently, perhaps because of the lack of interdisciplinary research teams or necessary funding (Luukkanen, 1994).

3.7.4 Input-Output Models

Input-output energy models provide more sectorial level detail than macroeconomic models. In input-output models, energy demand depends also on the changes in different economic sectors and industrial structure, not only GDP growth. However, input-output models are based on historical data, and unlike real economic systems that are dynamic, these models struggle to predict structural changes and the long-term future (Luukkanen, 1994).

3.8 Scenario Analysis

Scenarios are self-consistent story-lines of how future energy system might evolve overtime in a particular socio-economic setting and under a particular set of policy conditions. Scenarios can be built and then compared to assess their energy requirements because unlimited number of “what if” questions can be tested, such as what if more housing unit have access to electricity, what if different electricity expansion plans are pursed and more such what if question to better understand the future energy road map. In this study realistic, best and ideal scenarios were developed to provide an alternative energy mix for 2050 (Spalding-Fecher, Brian, & Harald, Climate change and hydropower in the Southern African Power, 2016).

3.8.1 Realistic Scenario

In this study, the Realistic Scenario is constructed from data that is representative of what the reality might be in 2050.In this scenario most of the growth key drivers are projected based on reported projected Figures for 2035 which are then extended to 2050 (Central Statistical Office, July 2013). Table 19 show the main driver used to construct the realistic scenario for the target year 2050.In leap software the data in Table 20 are responsible for energy demand growth while the internal calculation add the power plants from various primary energy sources to meet the demand

Table 19: Realistic Scenario Key Drivers

No.	KEY DRIVER	BASE YEAR 2015	GROWTH RATES	SIMULATION YEAR 2050
1	Gross Domestic Product (Billion $)	21.5	4-10percent	518.72
2	Population (Million)	15.47	2.7percent	39.38
3	Number of Households (Million)	3.00	2.7	7.62
4	Household Size	5.2	-	5.2
5	Urbanization	47.7percent		52percent
6	Electricity Accesses (Urban)	40.50percent		90percent
7	Electricity Accesses (Urban	59.50		55percent

3.8.2 Best Scenario

In the best scenario most of the growth key drivers are expected to escalate at a rate better than the realistic scenario. This scenario is what the best development path the country would attain in all of its econometric and demographic parameter set by this research. Table 20 show the main driver used to construct the best scenario for the target year 2050.In leap software the data in Table 20 are responsible for moderate energy demand growth while the internal calculation add the power plants from various primary energy sources to meet the demand

Table 20: Best Scenario Key Drivers

No.	KEY DRIVER	BASE YEAR 2015	GROWTH RATES	SIMULATION YEAR 2050
1	Gross Domestic Product (Billion $)	21.5	6-15percent	606.42
2	Population (Million)	15.47	2.7percent	51.67
3	Number of Households (Million)	3.00	2.7	10.00
4	Household Size	5.2	-	5.2
5	Urbanization	47.7percent		55percent
6	Electricity Accesses (Urban)	40.50percent		95percent
7	Electricity Accesses (Urban	59.50		50percent

3.8.3 Ideal Scenario

Under this scenario, the highest growth rate of econometric parameters were used. It is expected that the country’s development will be the highest of the three scenarios and as such, optimistic approach to estimation Figures of the key driver’s Figures were used.

Table 22 show the main driver used to construct the ideal scenario for the target year 2050.In leap software the data in Table 21 are responsible for high energy demand growth in this scenario, while the internal calculation add the power plants from various primary energy sources to meet the demand .

Table21: Ideal Scenario Key Driver

No.	KEY DRIVER	BASE YEAR 2015	GROWTH RATES	SIMULATION YEAR 2050
1	Gross Domestic Product (Billion $)	21.5	6-15percent	671.45
2	Population (Million)	15.47	2.7percent	57.8
3	Number of Households (Million)	3.00	2.7	11.07
4	Household Size	5.2	-	5.2
5	Urbanization	40.5percent		58percent
6	Electricity Accesses (Urban)	40.50percent		95percent
7	Electricity Accesses (Urban	59.50		75percent

3.9 General Assumptions

I. The population for the base year 2015 is taken as 15,473,905 according to the Central Statics Office report of population projection (Central Statistical Office, July 2013). In the projection for 2035 the report projected the population at the growth rate of 2.8 percent up 2035.This study extends the population growth projection to 2050 at different rate in the three scenario.

II. The urbanization trend projection for 2035 is 46.1percent according to the central statistics report. In this study urbanization for 2050 as shown above scenarios.

III. The nation access to electricity currently at 25percent will be different in each scenario.

IV. Gross National Income will be assumed to change by the same percentage points with Gross Domestic Product in all the three scenarios.

V. The energy demand in the industrial sector will be in line with the Gross Domestic Product growth rate. Household demand will be forecast from the activity level such as cooking lighting, refrigeration and heating per housing unit.

VI. The share of each primary energy contribution to the total energy mix shall be assumed based on the advancement of the technology conversion of the primary energy in Zambia and identified site potential for possible implementation.

3.9 Highlights from Methodology

In this chapter data was collected for this study and constructed three scenarios for target year 2050 energy map. This data was entered in LEAP tool software model and the result were represent in the next chapter.

CHAPTER FOUR: RESULTS

4.1 Introduction

This chapter presents the results of the energy mix simulation as elaborated in Chapter 3. Energy demand final units by sector area presented for each of the scenario with details of the energy map from 2015 with selected years up to 2050. The primary energy supply results are presented for all scenarios and the resulting primary energy mix scenarios. Then requirements for generation from all fuels and power plant output by fuel will be presented. Further, reserve margin and capacity added to the power system are also be present.

4.2 Energy demand

The energy demand from 2015 to 2050 for three scenarios constructed are presented in Figure 11.

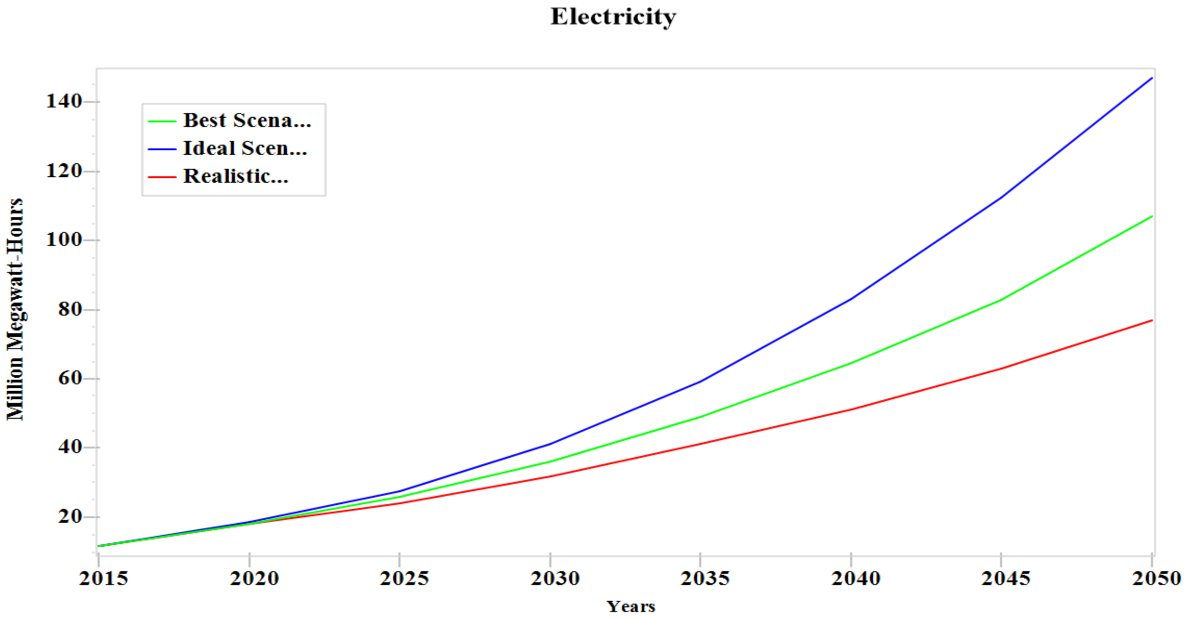


Figure 11: ***Graphical Results of Energy Demand Final Units***

Table 22 supplements the graphical presentation of the final energy demand from 2015 to 2050 for all the scenarios in Figure 14 with actual energy Figures in a five year intervals.

Table 22: Final Energy demand million (MWh)

SCENARIOS	YEARS							
Scenarios	2015	2020	2025	2030	2035	2040	2045	2050
Best Scenario	11.680	18.060	25.923	36.214	49.088	64.448	82.731	106.972
Ideal Scenario	11.680	18.508	27.565	41.193	59.228	83.218	112.328	146.980
Realistic Scenario	11.680	18.218	24.035	31.696	41.168	51.131	62.948	76.920

Figure 12 shows the graphic representation of final energy (Electricity) demand by sector for the realistic scenario of selected years between 2015 and 2050.

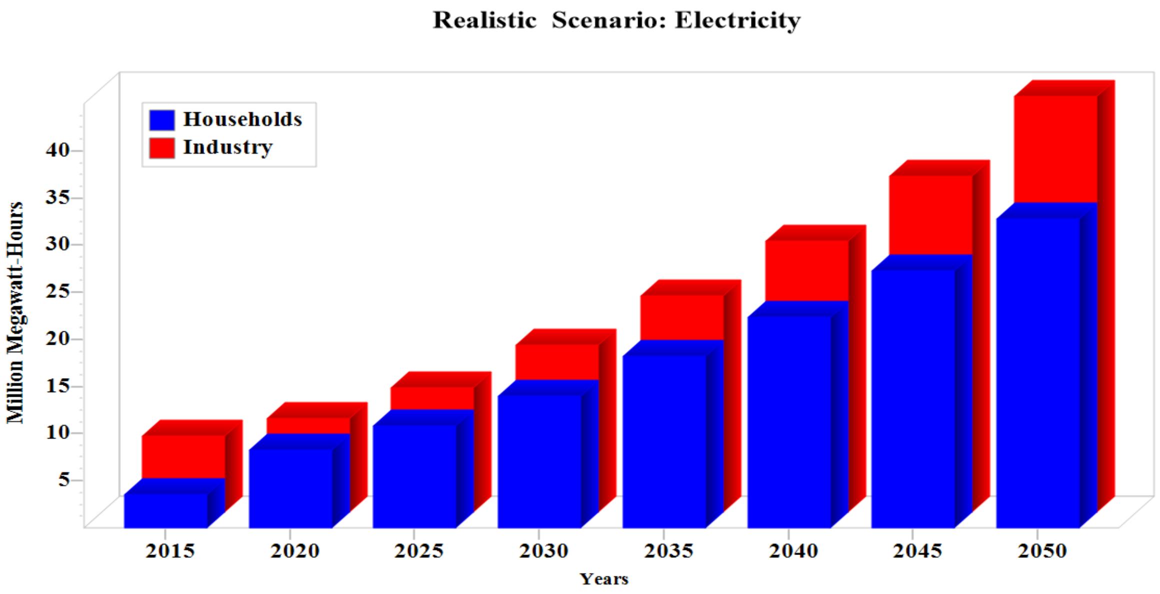


Figure 12: ***Realistic Scenario Graphic Results of Energy Demand by Sector***

Figure 13 shows the graphic representation of final energy (Electricity) demand by sector for the best scenario of selected years between 2015 and 2050.

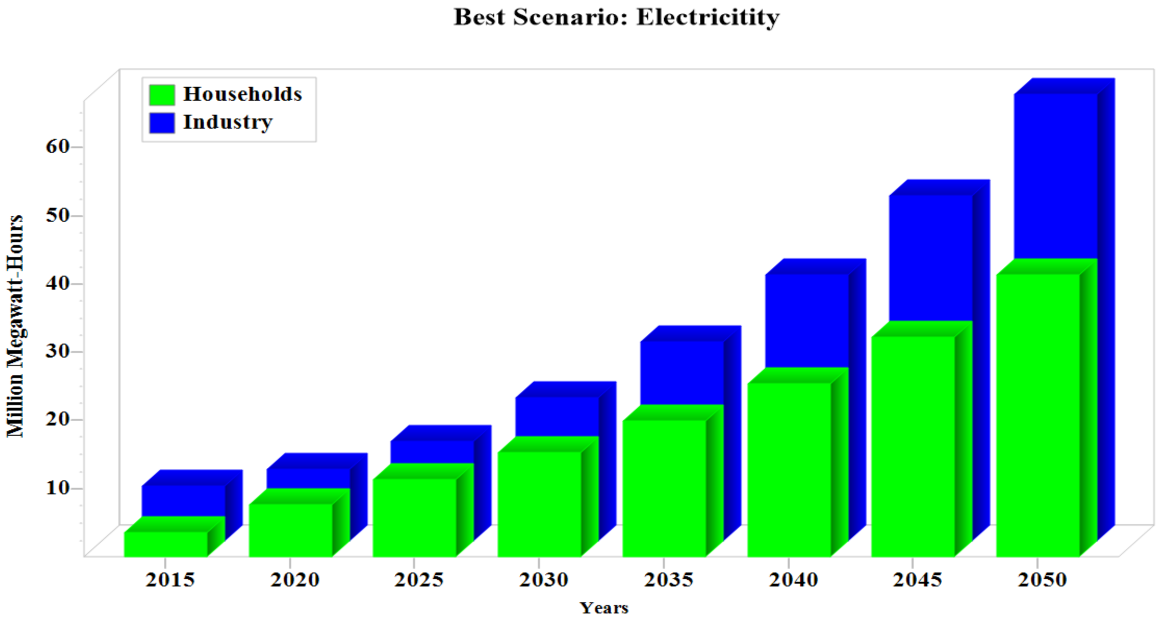


Figure 13*: Best Scenario Graphic Results of Energy Demand by Sector*

Figure 14 shows the graphic representation of final energy (Electricity) demand by sector for the ideal scenario of selected years between 2015 and 2050.

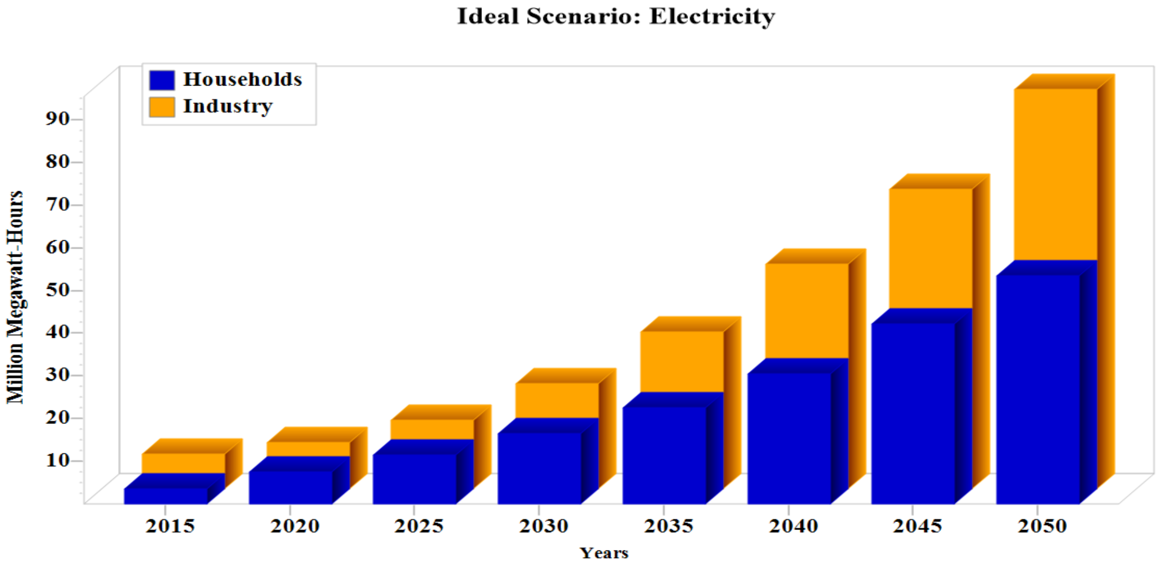


Figure 14*: Ideal Scenario Graphic Results of Energy Demand by Sector*

4.3 Energy Supply

Figure 15 presents primary energy supply modeling results from 2015 to 2050 for all three scenarios considered.

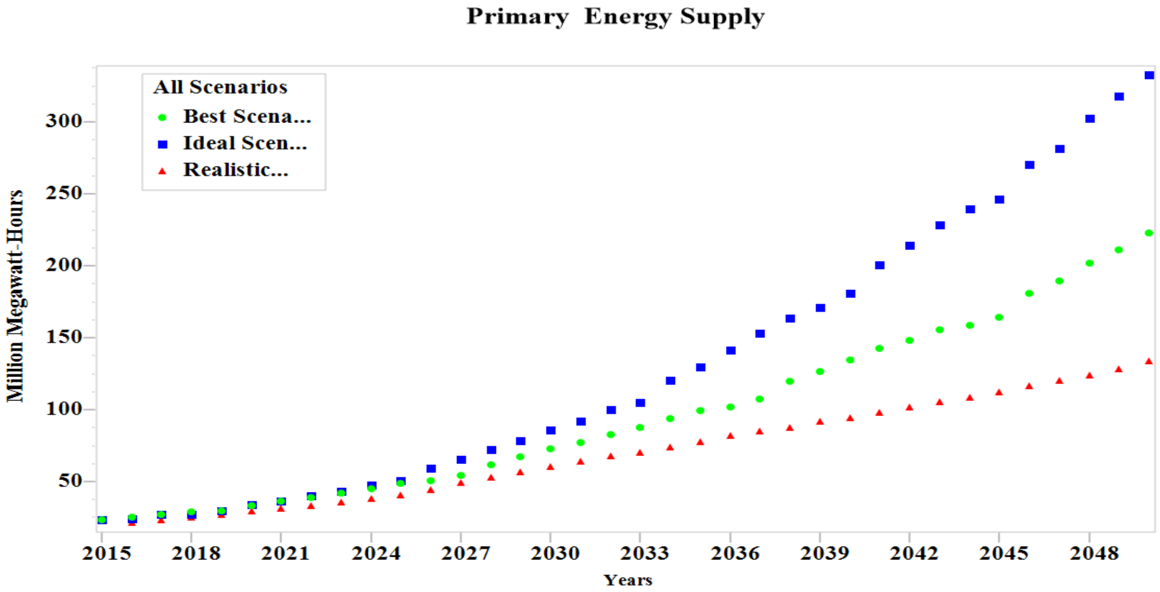


Figure 15*: Primary Energy Supply Requirements all Scenarios*

Table 23 supplements the graphical presentation of the primary energy supply requirement for all scenarios in Figure 18 with actual energy Figures in a five year intervals from 2015 to target year 2050.

Table 23: Primary Energy Supply Requirement in million-MWh for all Scenarios

SCENARIOS	**YEARS**							
	2015	2020	2025	2030	2035	2040	2045	2050
Best Scenario	22.9	31.4	47.6	70.5	99.5	134.1	172.9	222.8
Ideal Scenario	22.9	32.8	53.1	83.2	124.6	182.4	246.1	332.4
Realistic Scenario	22.9	32.6	46.0	62.1	82.3	101.1	126.3	133.4

Figure 16 presents the primary energy supply mix in the realistic scenario used for electricity generation from the base year 2015 to end year 2050. In this scenarios, Hydropower, thermal coal, Biomass, bagasse solar and wind formed the energy mix in 2050.

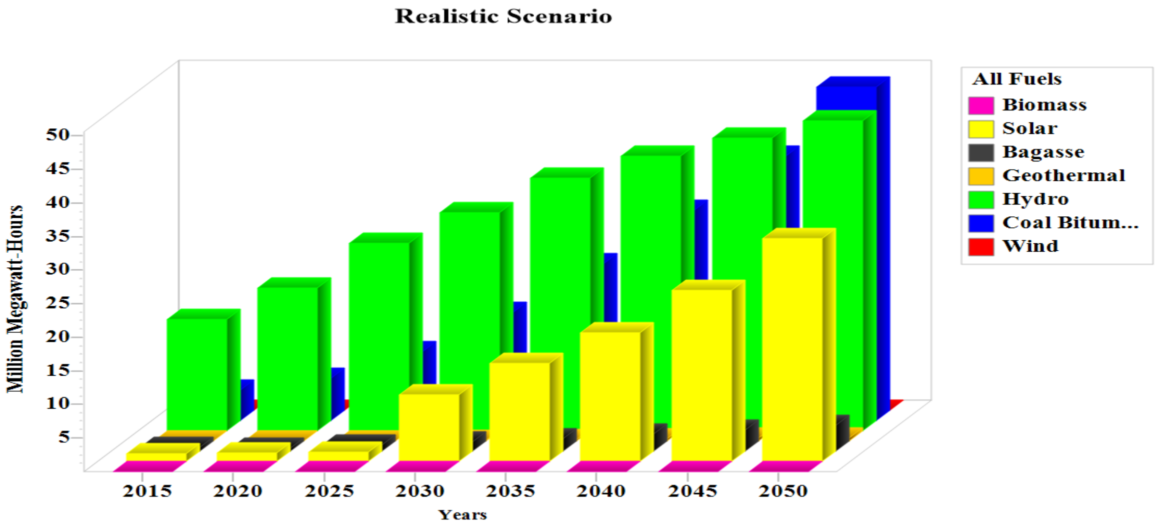


Figure 16*: Primary Energy Supply Mix Realistic Scenario*

Figures 17 shows primary energy supply mix in the best scenario used for electricity generation from the base year 2015 to end year 2050. In the best scenario, hydropower thermal coal, solar, biomass, bagasse, geothermal and wind energy were the primary energy mix for 2050.

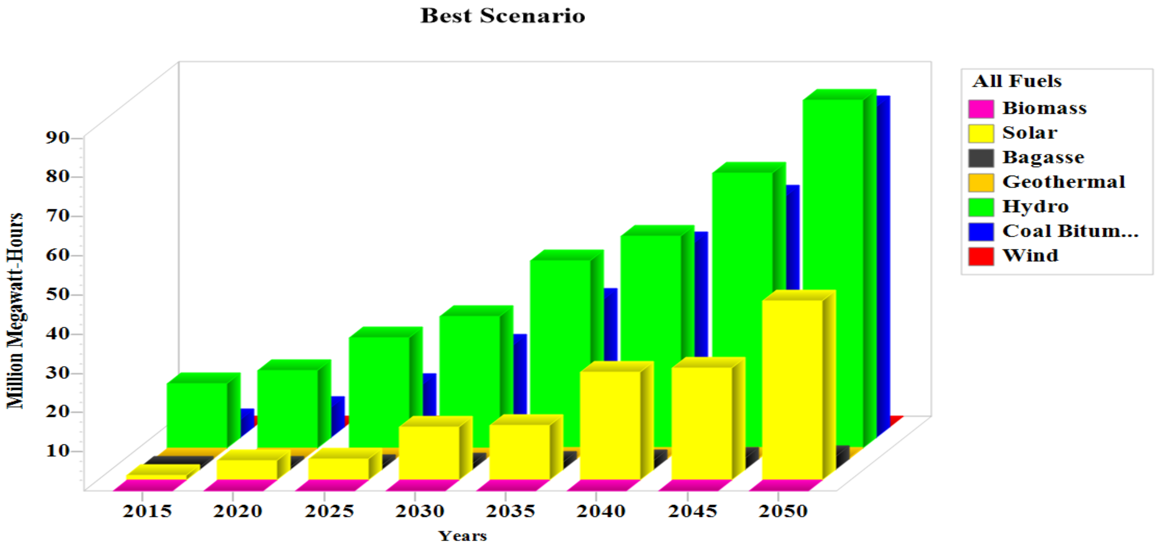


Figure 17*: Primary Energy Supply Mix Best Scenario*

In Figures 18 shows primary energy supply mix in the ideal scenario used for electricity generation from the base year 2015 to end year 2050. In this scenario, again hydro power, thermal coal, solar, Biomass, bagasse, geothermal and wind energy was 2050 primary energy mix.

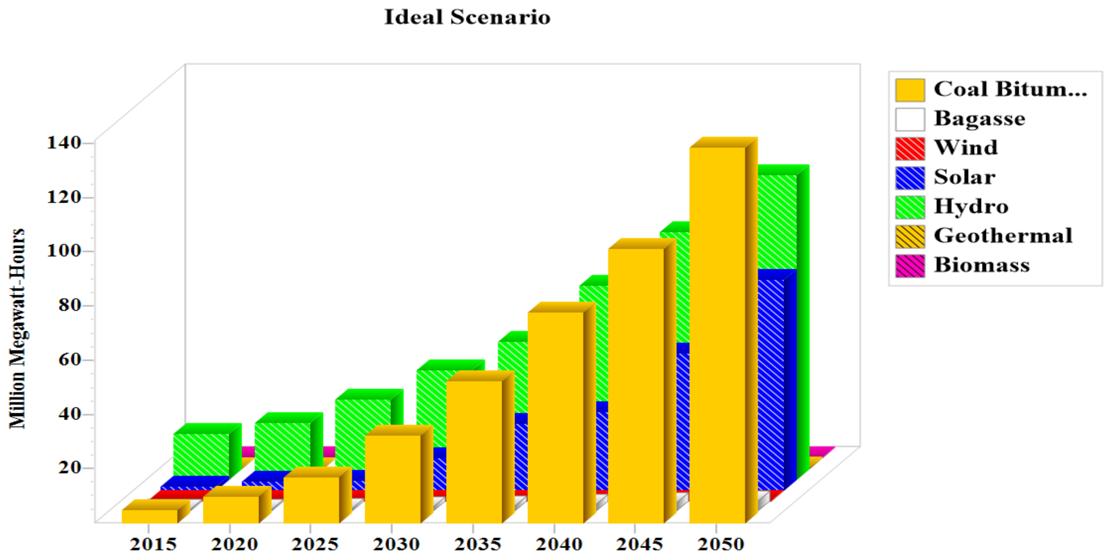


Figure 18***: Primary Energy Supply Mix 2015-2050***

4.4 Generation

Table 24 supplement Figure 18 on the required generation from all available fuels in the three scenarios over a five year internal from 2015 to 2050.

Table 24: Required generation from all fuels in million MWh

SCENARIOS	YEARS							
	2015	2020	2025	2030	2035	2040	2045	2050
Best Scenario	13.741	21.247	30.498	42.604	57.751	75.821	97.331	125.849
Ideal Scenario	13.741	21.774	32.429	48.462	69.680	97.904	132.150	172.917
Realistic Scenario	13.741	21.433	28.276	37.289	48.433	60.154	74.057	90.494

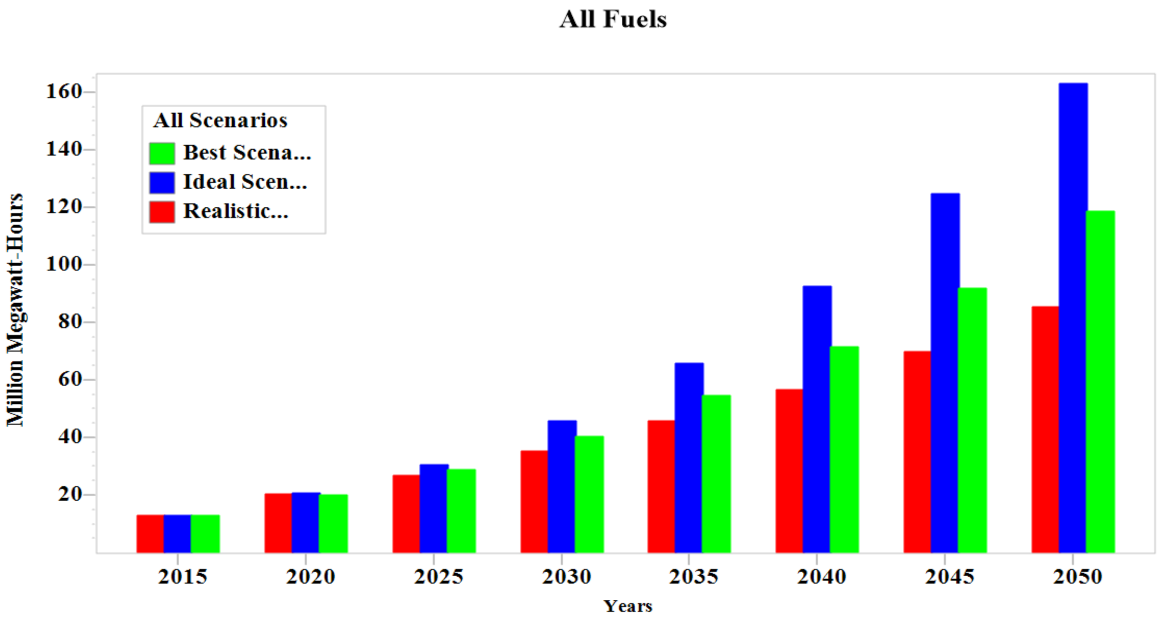


Figure 19*: Requirements for generation from all fuels*

Table 25 presents the projected national installed plant capacities in five year intervals which will support the energy demand and primary energy requirement for all the scenarios.

Table 25: Expected installed generation capacity in megawatts (MW) for all scenarios

SCENARIOS	YEARS						
	2020	2025	2030	2035	2040	2045	2050
Best Scenario	6,212	8,716	11,684	16.016	20,622	26,661	34,110
Ideal Scenario	6,212	9,112	13,638	20,136	26,687	36,236	46,939
Realistic Scenario	6,212	7,901	10,302	13,618	16,833	20,396	24,646

The performance of the various energy generation plants are shown in Figures 20 to 22. New future power plants that is Batoka, Mpata, Devils Gorge and Kafue Gorge power station are expected to be the main generating stations which must be added to the existing generation facilities for the nation.

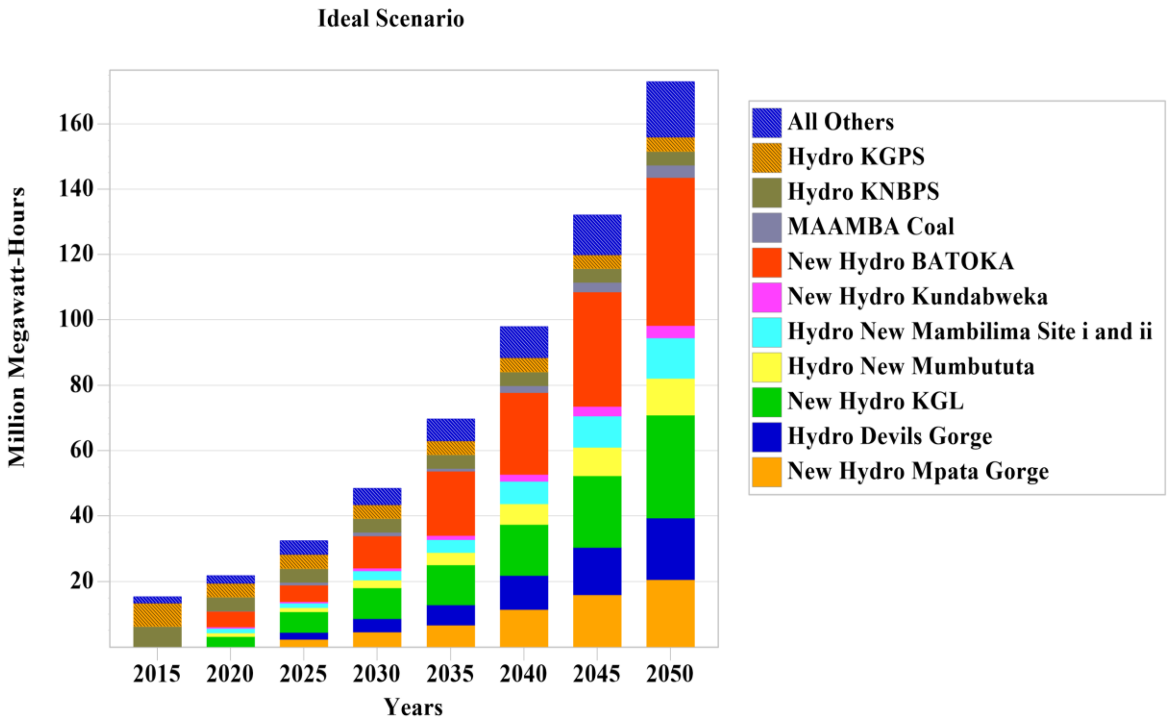


Figure 20*: Power plant output by fuel*

The results show that there will be less contribution of generation from the existing big power plants such Kariba North and Kafue Gorge. However, since hydro power plants have proved to exist for more than 100 years, it is therefore expected that the two plants could still be able to contribute significantly if refurbishments are carried at the correct intervals.

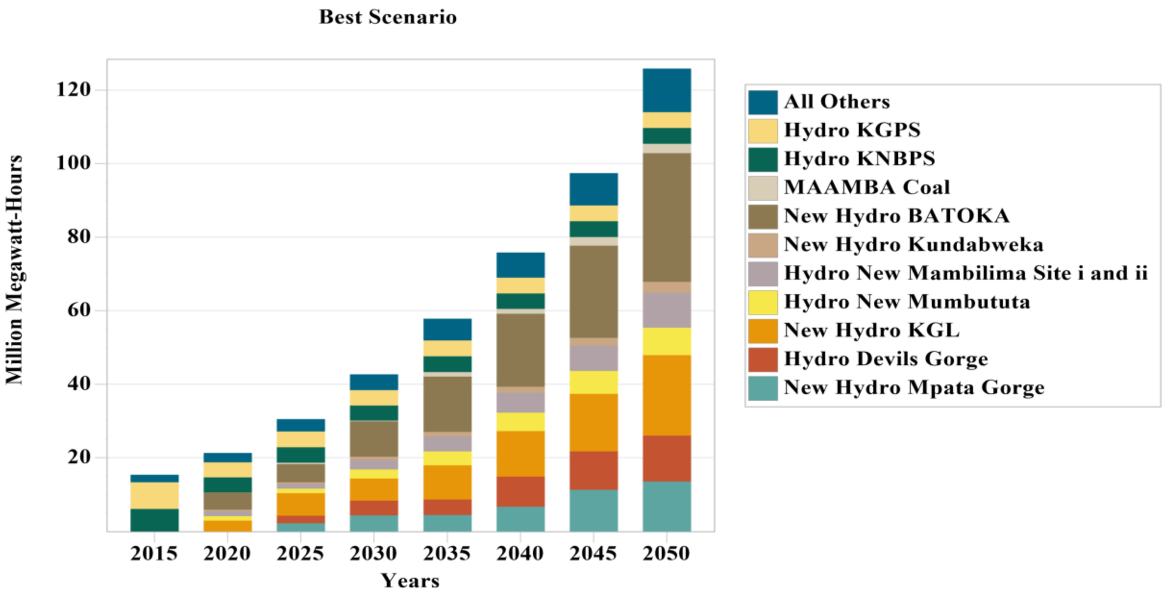


Figure 21*: Power plant output by fuel*

In all the scenarios all, solar and plants with capacities less than 200MW are combined and captured as all other plants. Some plants with big capacities are added to the generation capacity in phases as and when the demand has gone up in the energy demand simulation side in the model.

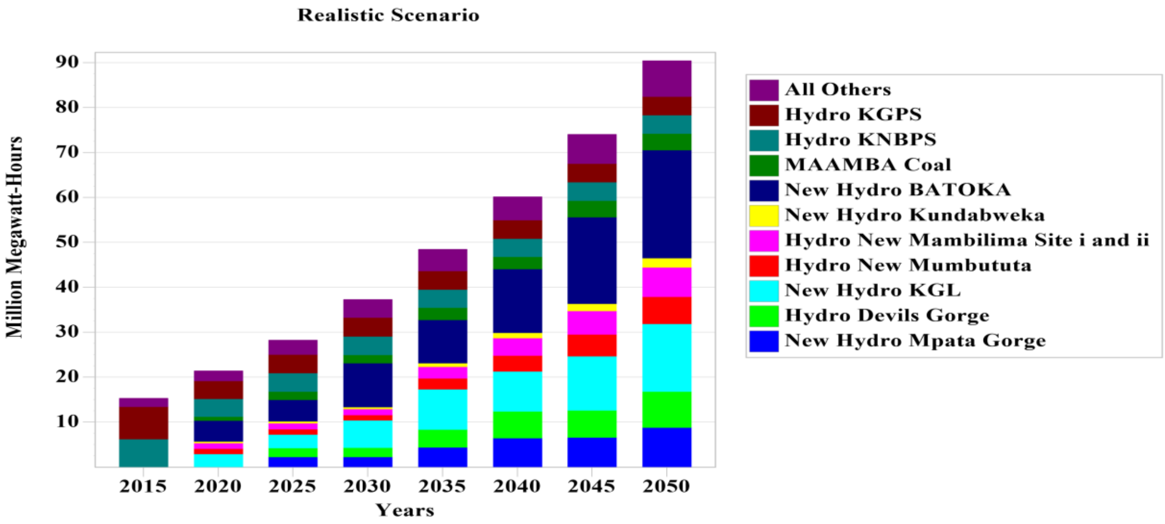


Figure 22*: Power plant output by fuel*

4.4.1 Reserve margin

The graph of the reserve margin is shown in Figure 23 for base year 2015 to end 2050. Southern African power pool set the power system reserve margin for the member state. In capacity terms, reserve margin is the capacity of the largest unit on the power system and the operation of the power system should be operated with less than the capacity of largest unit, such that a tripping of a unit should not cause the network to collapse.

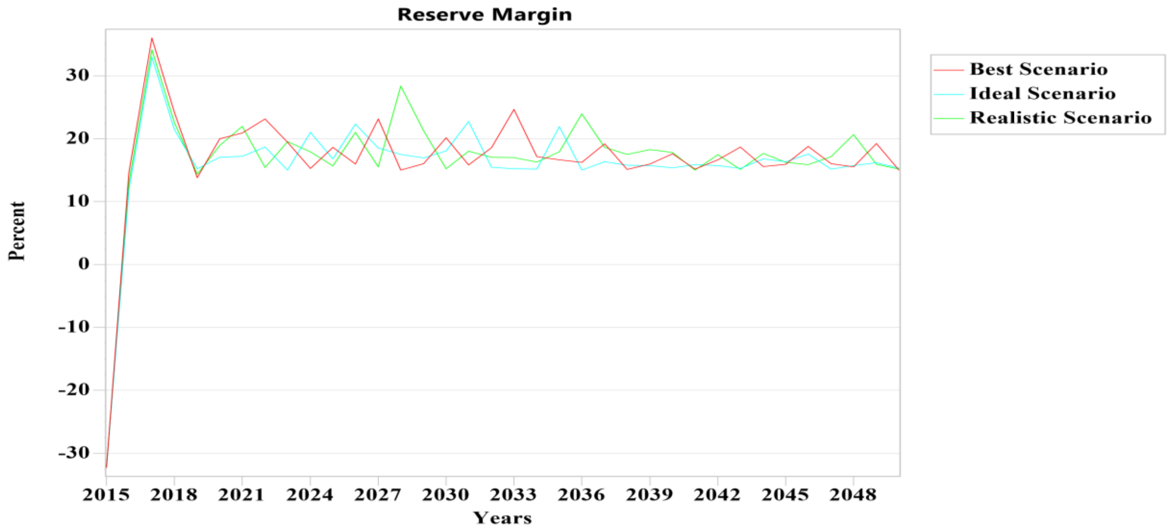


Figure 23*: Expected Power System reserve margin*

Figures 27 to 29 shows how the future plants identified in the literature are added to the energy system requirement from base year to one before the end year in the leap model, for the realistic, best and ideal scenarios.

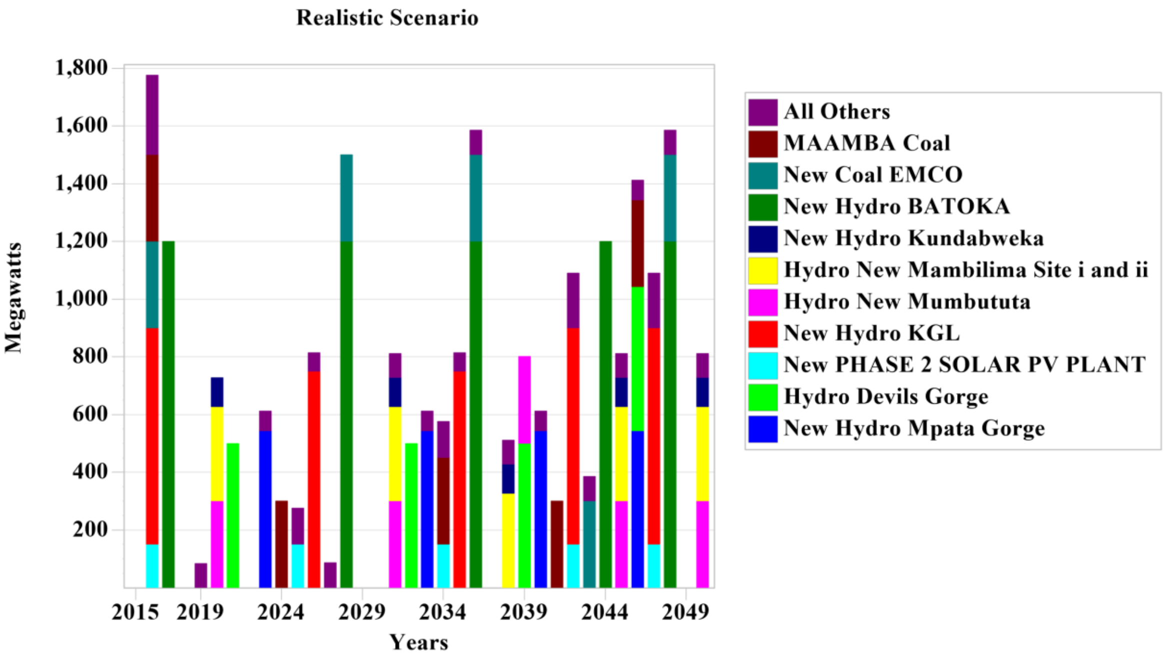


Figure 24*: Plant Capacity Added in Realistic scenario*

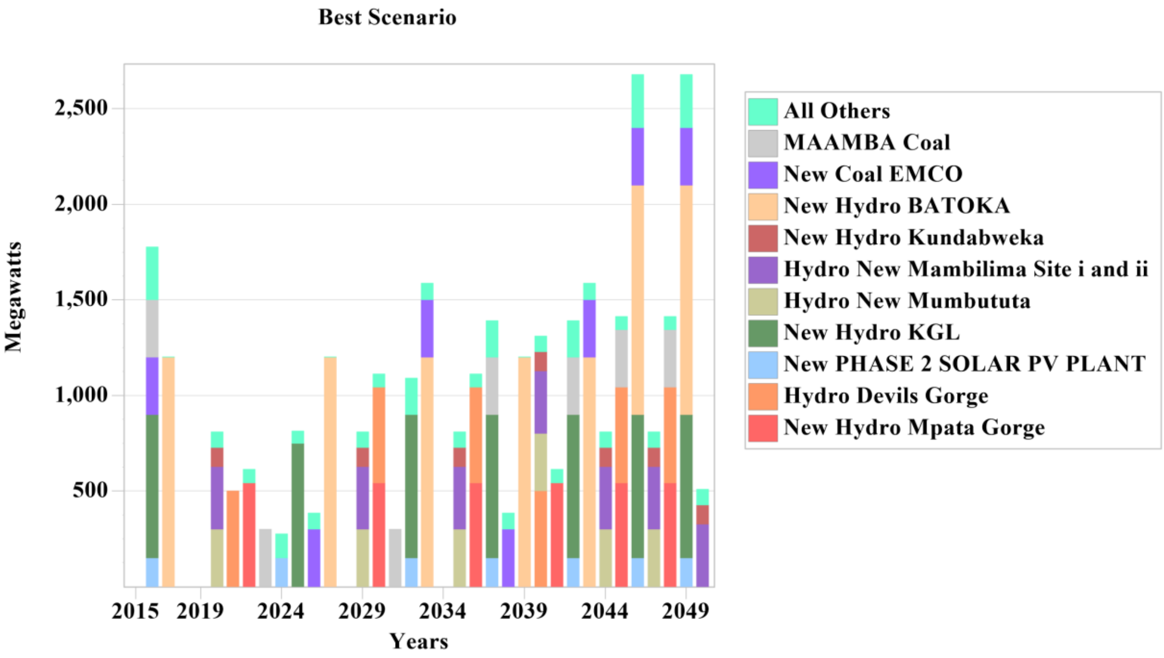


Figure 25*: Plant Capacity Added in Best Scenario*

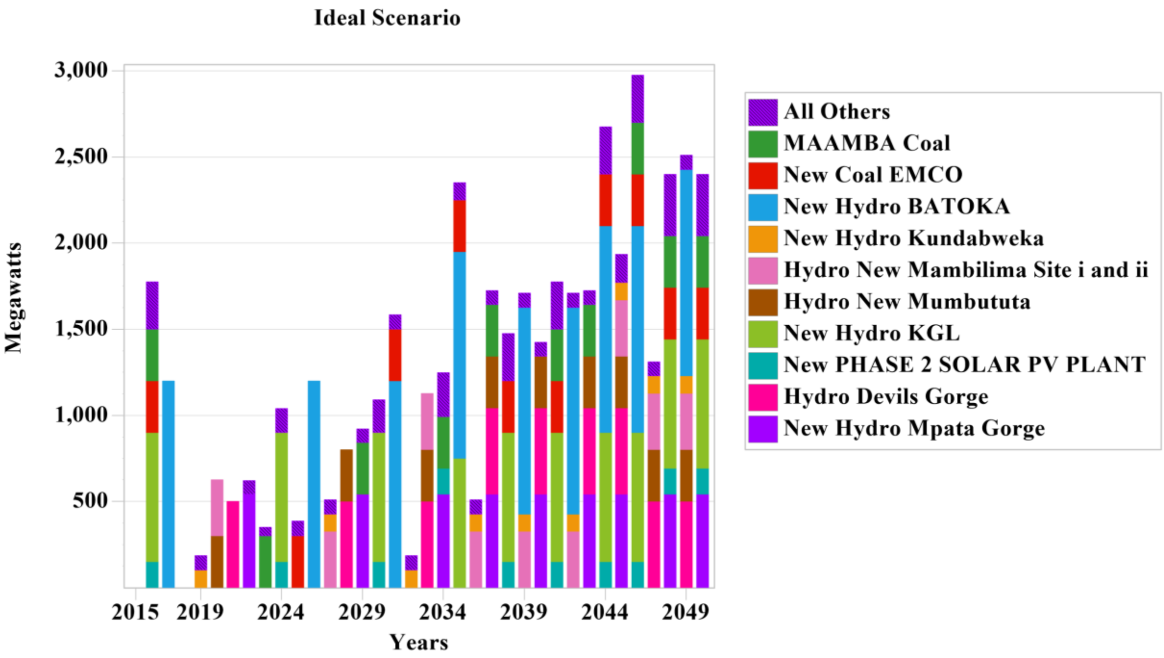


Figure 26*: Plant Capacity Added in ideal scenario*

This chapter presented the results of Zambia's energy mix for 2050 simulated using the LEAP tool software. The next chapter will discuss and explain these results in detail.

CHAPTER FIVE: DISCUSSION

5.1 Introduction

This chapter discusses the results of the energy mix simulation presented in Chapter 4. Energy demand final units by sector are discussed for each of the scenario from 2015 with selected years up to 2050. The primary energy supply results are explained for all scenarios and the resulting primary energy mix scenarios. Requirements for generation from all fuels and power plant output by fuel are detailed in this chapter. Reserve margin and capacity added energy system are also be discussed. The chapter concludes with the discussion on the energy flow and balance from 2015 to 2050.

5.2 Energy demand

The energy demand from 2015 to 2050 for all scenarios considered are presented in Figure 27..This graph show similar energy demand in all scenarios until after the year 2022 due to the different key driver parameters used to construct the scenarios.

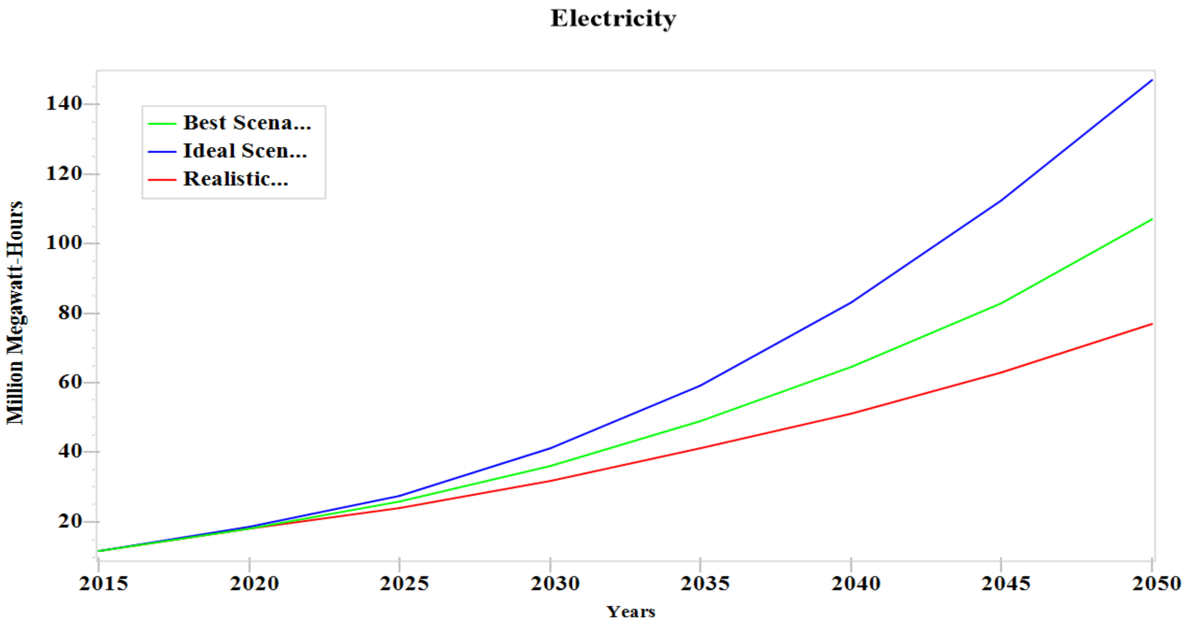


Figure 27*: Graphical Results of Energy Demand Final Units*

From Table 26 increase in final energy usage is 6.4 times the base year 2015 base consumption in the realist scenario. While increments are 12.5 times in the ideal scenario and 8.9 times more in best scenario respectively, compared to the base consumption. Energy consumption stood at 11.680 million MWh in base 2015 and increased to 76.920 million MWh in the realistic, 106.972 in the best, and 146.980 million MWh in the ideal scenarios respectively.

Table 26: Final Energy demand in MWh

SCENARIOS	YEARS							
Scenarios	2015	2020	2025	2030	2035	2040	2045	2050
Best Scenario	11.680	18.060	25.923	36.214	49.088	64.448	82.731	106.972
Ideal Scenario	11.680	18.508	27.565	41.193	59.228	83.218	112.328	146.980
Realistic Scenario	11.680	18.218	24.035	31.696	41.168	51.131	62.948	76.920

5.3 Energy Supply

The various forms of primary energy supply were readily available to support the energy conversion required by the final energy demand. In Figure 27 below, Ideal scenario required the biggest quantity of primary energy, followed by best scenario and realistic scenario. This behavior in line with the final energy demand graph in Figure 30 above.

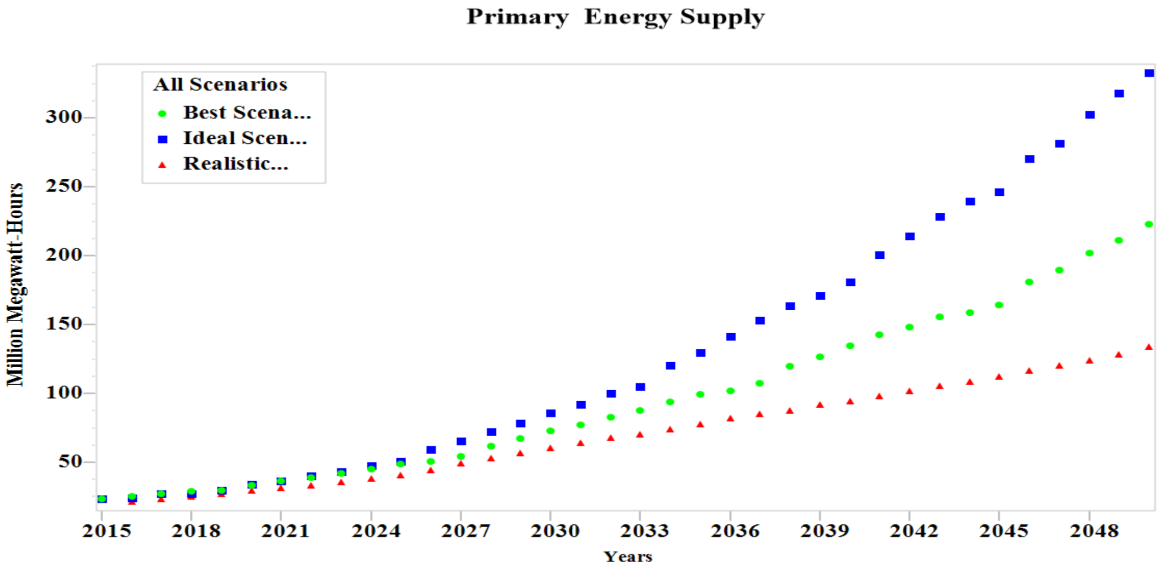


Figure 28***: Primary Energy Supply Requirements all Scenarios***

From Figure 28 and Table 27, it can be seen that total primary energy required increases between 700 to 1500 percent. Primary energy requirement was 22.9 million MWh in 2015 and increased 133.4 million MWh in there Realistic, 222.8 million MWh in Best and 332.4 million MWh in ideal scenarios respectively, by 2050. In the first five years primary energy supply is almost similar in all the three scenarios, but at the turn of 2022, changes take shape in accordance to econometric parameter driving usage of primary energy.

Table 27: Primary Energy Supply Requirement in Million-MWh for all Scenarios

SCENARIOS	**YEARS**							
	2015	2020	2025	2030	2035	2040	2045	2050
Best Scenario	22.9	31.4	47.6	70.5	99.5	134.1	172.9	222.8
Ideal Scenario	22.9	32.8	53.1	83.2	124.6	182.4	246.1	332.4
Realistic Scenario	22.9	32.6	46.0	62.1	82.3	101.1	126.3	133.4

Figures 29 shows primary energy supply mix by share in the realistic scenario. Hydro power and thermal coal contributed 34.6 and 37.2 percent respectively, followed by solar at 24.9 percent. Biomass, bagasse, geothermal and wind energy contributed 3.3 percent. A higher coal share attributed to the slow addition of hydro plants to the energy system.

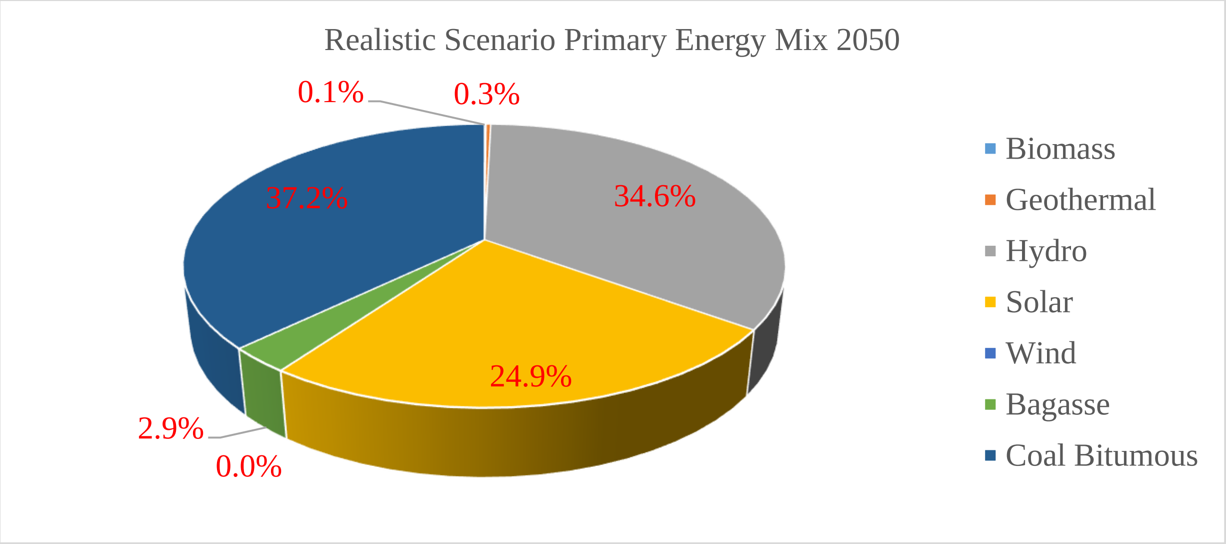


Figure 29: ***Primary Energy Supply Mix 2050 Realistic Scenario***

Figures 30 shows primary energy supply mix by share in the best scenario. Hydro power and thermal coal contributed 39.8 and 38 percent respectively, followed by solar at 20.6 percent. Biomass, bagasse, geothermal and wind energy contributed 1.6 percent. Solar contribution was less than 25 percent due to high penetration of hydro and coal. Share of geothermal and wind was small, because these resources are sufficient as alluded to in the literature review.

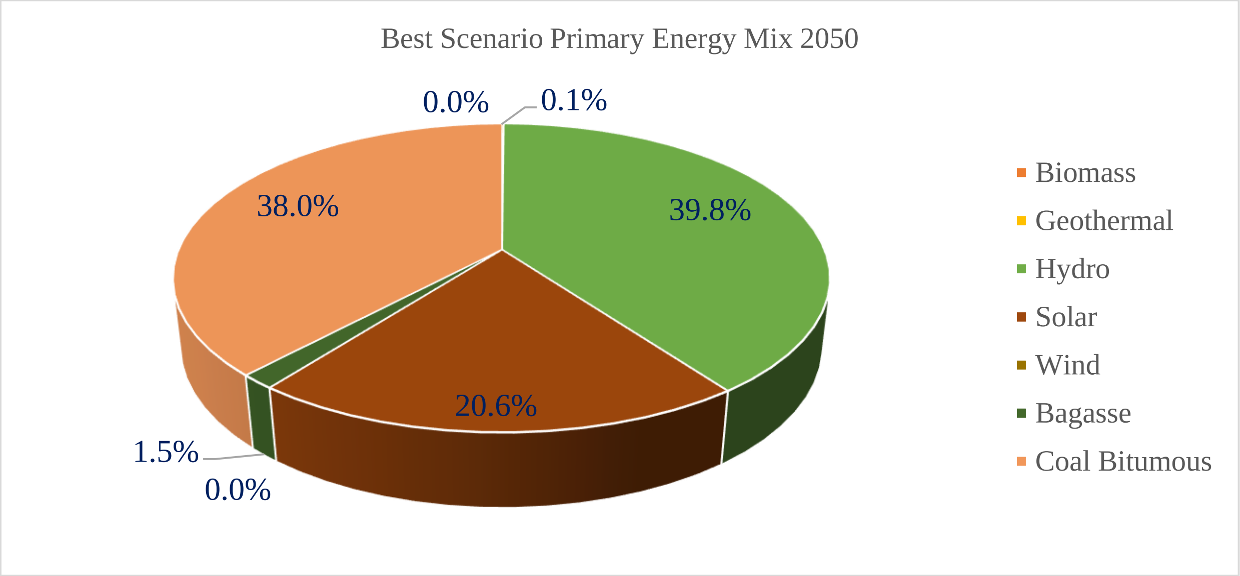


Figure 30: ***Primary Energy Supply Mix 2050 Best Scenario***

Figures 31 shows primary energy supply mix by share in the ideal scenario. Hydropower contributed 33.7 percent indicating that all available hydro site were fully developed. Coal contribution of about 41.7 percent, indicates that available reserves were being extracted to meet required primary energy supply. Solar contribution of 23.4 percent penetration was the optimum as per the literature review. Biomass, bagasse, geothermal and wind energy contributed 1.11 percent. Energy supply from bagasse at 1.1 percent could be scaled up in future, by replacement of the low-pressure boilers with high-pressure boilers. This could increase the potential of biomass contribution in the 2050 energy mix.

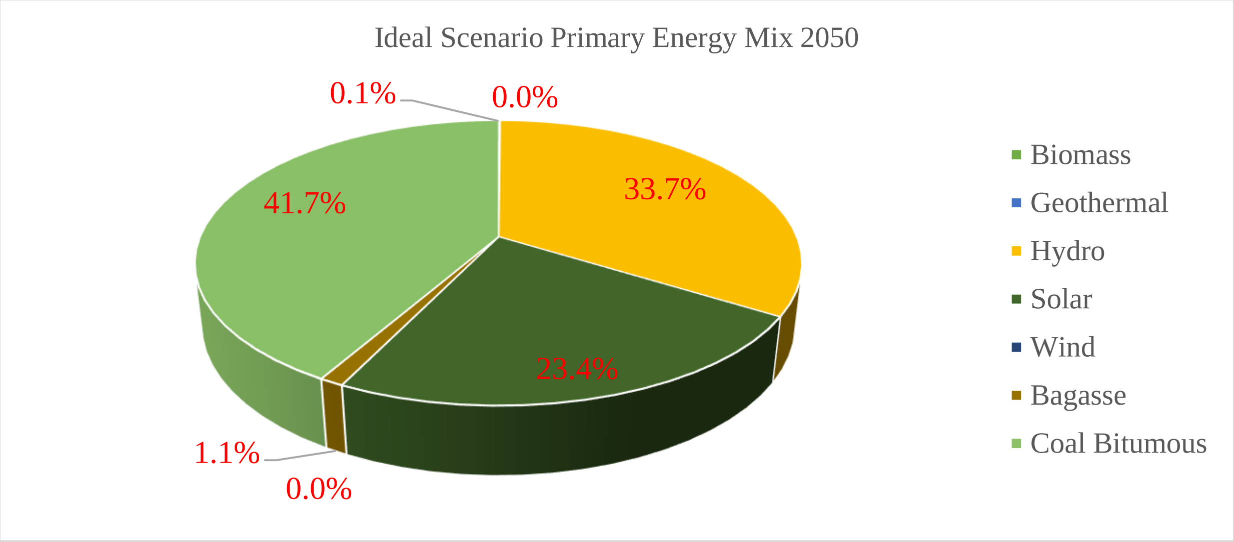


Figure 31*: Primary Energy Supply Mix 2050 Ideal Scenario*

5.4 Reserve margin

The graph of the reserve margin shown in Figure 32 shows that from 2015 the power system has been operating below the set Southern African power pool reserve margin of less than Zero but after addition of plant capacity the reserve margin improves to above 30 percent. It then drops and raises in accordance to demand and plant capacity expected to be available in all the scenarios. The reserve margin is in agreement with expected plant capacity addition results, presented in chapter 4.

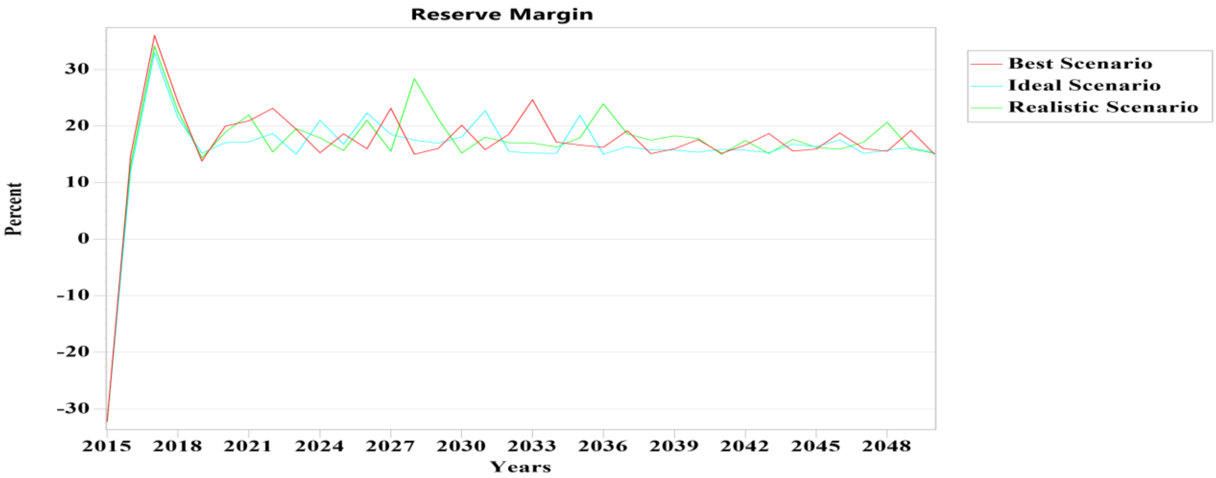


Figure 32*: System expected reserve margin*

5.5 Energy balance

The energy balance in Figures 33 to 35 is consistent in the all three scenarios and shows that in 2015 there was sufficient energy going by the plant capacities shown in Figures 27 to 29 in chapter 4 and the demand shown in Figure 30. However, 2015 is the year in which we experienced load shedding due to the depleted primary energy in dams and rivers. This can be explained by some of the small plants whose availability was in real sense very low because plant efficiency were at record low due to the fact they had never being refurbished from the time of commissioning 50 years ago.

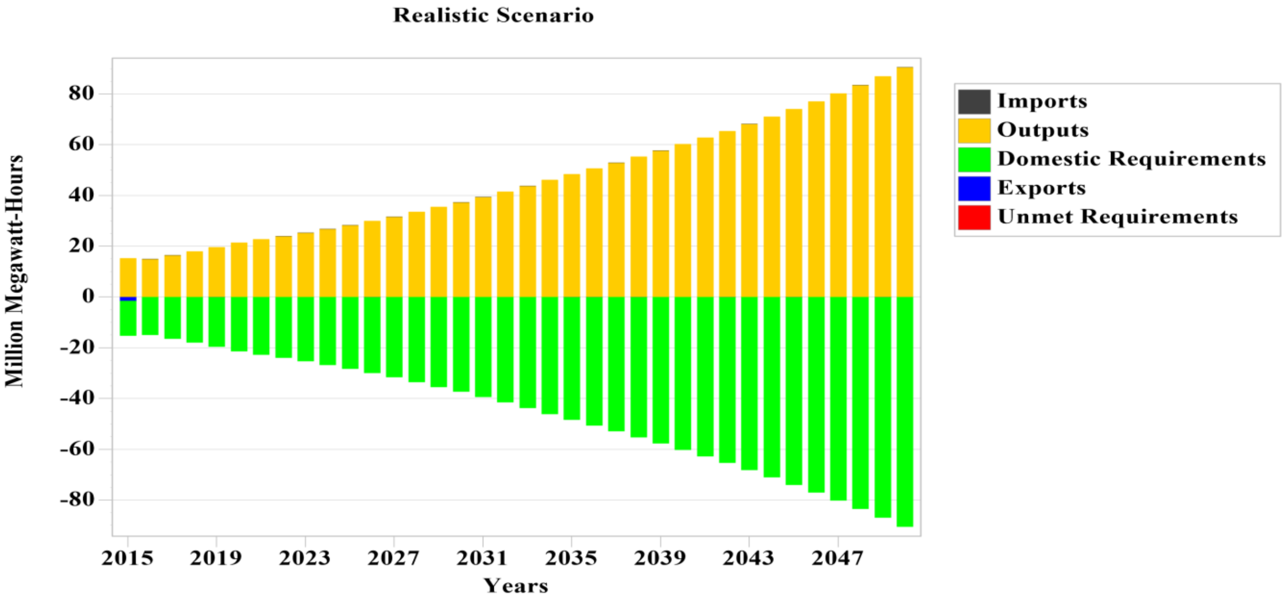


Figure 33***: Energy balance Realistic Scenario***

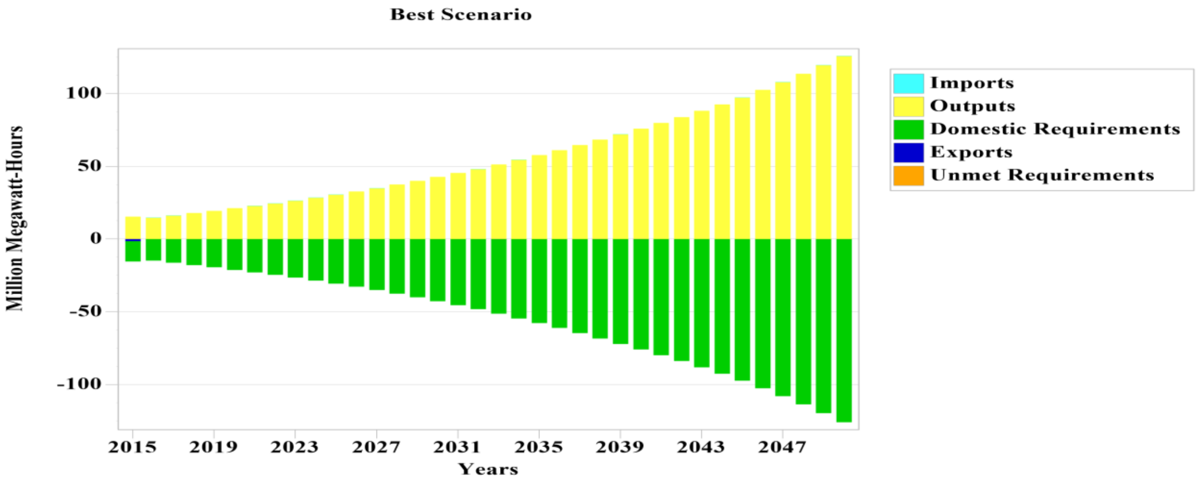


Figure 34***: Energy balance best scenario***

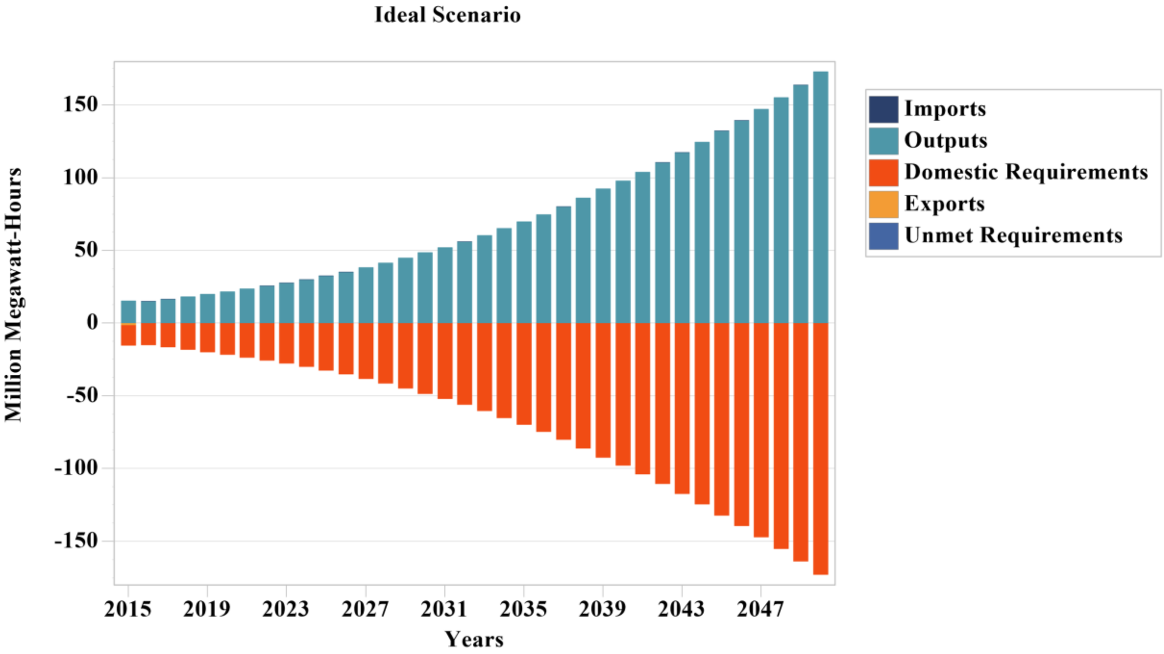


Figure 35***: Energy balance ideal scenario***

The energy balance in all scenarios is acceptable with small energy imported in a few selected years. This chapter discussed the primary energy mix for three constructed and modeled scenarios. The next chapter makes conclusion and the recommendation of the study outcome.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

1. In this study' primary energy supply options for 2050 energy mix penetration shares for all scenarios was hydro (33-39.8) percent, coal (37.2-41.7) percent , solar(20-24.7) percent and bagasse (1.1-2.9) percent. Biomass, geothermal and wind energy had less 1 percent share penetration. There is still unexploited biomass and biogas, which can contribute to primary energy supply mix. Although the country has fuel source for nuclear energy, the simulation results indicate that nuclear energy is not yet one of the option in the period leading up to 2050.The country exploit all its renewable first before adding nuclear energy to the energy mix
2. The final electric energy demand increases from 11.680 to 76.920 million MWh by 2050 in the realistic scenario. This increased demand is supported by the corresponding increment of 154.8 Million MWh of primary energy supply. Further the energy balance is consistent with results of both the energy demand and supply. In a few selected years the country might import energy if the capacity addition of the plants are not implemented according to the simulation results for plant performance and capacity addition of the identified generation plant. The scenario also suggests small energy, proving that we had adequate generation capacity in 2050 despite the depleted energy stocks in dams cause by the drought resulting in unparalleled load shedding the country experienced. This scenario could be the likely road map of the energy profile.
3. In the best scenario final energy demand increases from 11.680 to 106.972 million MWh in end 2050. There was a concomitant increment of primary energy supply of up to 226.1 million MWh. The energy balance graph was again consistent with results of both the energy demand and supply. Like the realistic scenario, the best scenarios also suggests small energy export as for reasons explained above. The country could import energy if the capacity addition of the plants are not implemented according to the simulation results for plant performance and capacity addition in few selected years
4. The increment of up to 146.980 million MWH of final energy demand with a corresponding increase in primary energy supply reaching 3828.9 million MWh was observed in the ideal scenario. The energy balance graph was once again consistent with results of both the

energy demand and supply with strong indication of self-energy suffice with little energy import should the generation plant capacity addition be implemented according to plant..

6.2 Recommendations

1. Solar energy utilization was lower in this study and it is recommended that solar and bio energy be scaled up to 25 percent of the installed capacity in the energy mix to shift away from hydro and coal dependence and further reduce chances of experiencing similar energy crisis like 2014 to 2016 period. Further, scaling up alternative energy mix improve the utilization of existing hydro power in that draining down of the energy stocks in the dam could be controlled by energy supplemented from other sources. The current operation of dams and rivers for power generation are such that the harvesting of water is done during rainy season between November and March and maximum retention is realized by the month of June. From July the flows starts reducing until the mid of the start of the next hydrological year. However, between the months of September to December maximum generation from solar could be afforded and effect optimized operation of the hydropower.

   The energy road map shows that the country may have sufficient energy and can avoid the 2015 energy crisis if capacity addition is systematically planned and primary energy mix is diversified as per the finding of this study scenario analysis.

2. In order for the results of this investigation to be applied in the decision making further work should then be carried out based on primary energy mix of this study. Therefore, studies should be carried regarding the economic potential and levelised cost of each of the primary energy option. The results of such a research can be feed in the decision-making framework.
3. The output of this investigation has adequately profiled the energy road map for not only the target year of study but also how the energy requirement changes between the base year and end year of the study. The results therefore serves as an input to the policy prescription required by policy maker to come up with sound plans. Energy modeling should be used in conjunction with financial models when prioritizing and scheduling energy project implementation for regions and nations. It could be concluded here that the current energy policy should include capacity addition based on simulated results.

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